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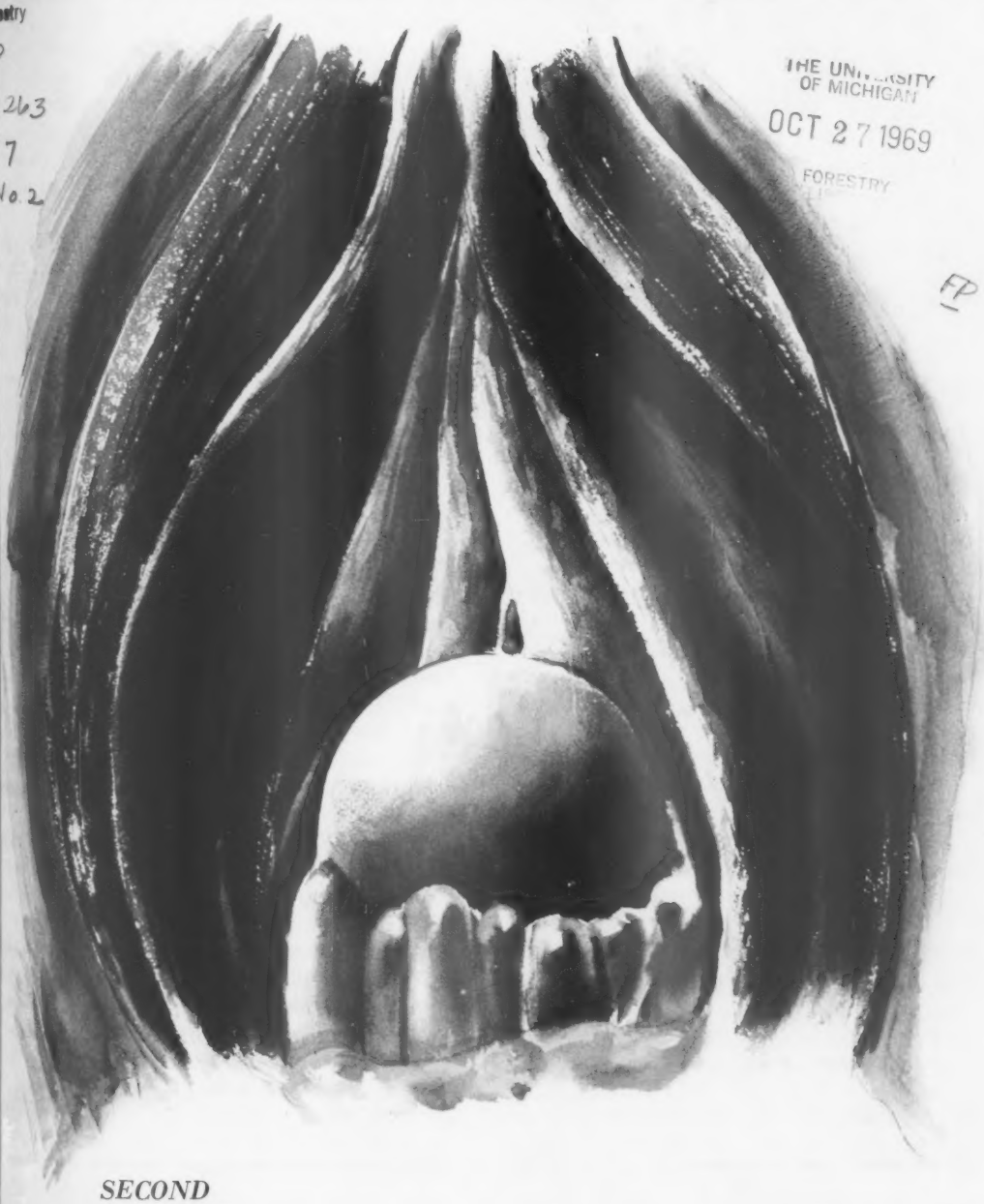

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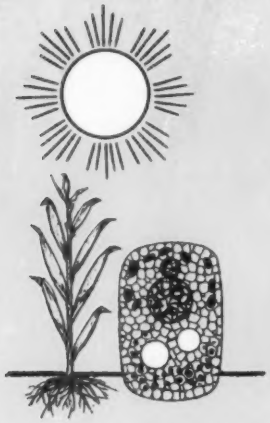

AGRICULTURAL SCIENCE REVIEW

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The Principle of Uncertainty

In 1927 the German physicist, Werner Heisenberg, proclaimed his "principle of uncertainty." He showed that every facet of nature contains some essential and irremovable uncertainty. If a scientist disregards this principle, he may falsely assume that only the limitations of time and money can separate him from a complete understanding of a cell, a plant, or a process. Such an attitude may serve to perpetuate a research system, even though added new knowledge may accumulate ever more slowly.

Author John Romberger properly recognizes the principle of uncertainty in his study of the apical meristems of trees. It was this recognition that helped in the successful development of *in vitro* culture of the minute meristematic tissue, which is shown so dramatically enlarged in the artist's conception on the cover of this issue.

All of this set us to thinking about how the principle of uncertainty affects other aspects of agriculture. The vagaries of the weather, of course, are well known. Then there are unexpected mutants, erratic behavior in cells, unexplained epidemics, and—in a more earthy vein—fickle bulls and stubborn mules.

Heisenberg's principle, however, deals more with the microelement of nature where uncertainty can become a very real hindrance to the search for new knowledge. A scientist must therefore rely on trends and make proper allowances for the irremovable uncertainties. In other words, he cannot accurately predict the future of, say, a chromosome, because he cannot be completely certain of its present.

To understand how Dr. Romberger coped with this strange situation in the microworld of a tree, we suggest readers pay particular attention to his commentary on "the burden of history."

Anyone who can master this concept will suddenly discover he is able to look at a tree through the eye of a physiologist. This changed viewpoint—plus the knowledge about nature's uncertainties—may very well engender a new sense of respect for both the profession and the object being studied.—W. W. K.

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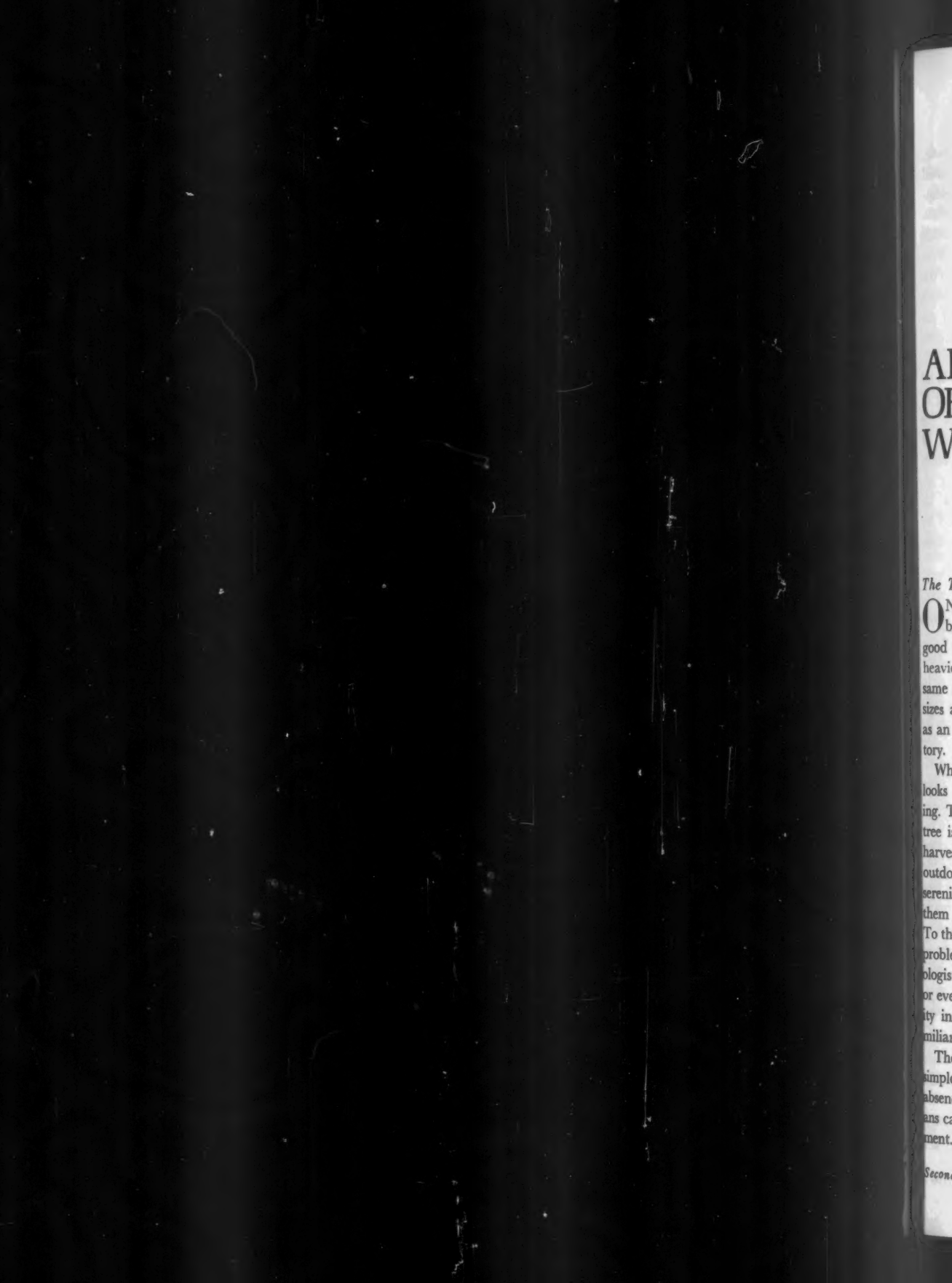

APICAL MERISTEMS OF TREES
Why We Study Them

by JOHN A. ROMBERGER

The Tree as Organism and Society

ON rocky and windy mountain slopes, trees may be small and tortured-looking, like *bonsai*. On good sites they may develop into the largest and heaviest of all living organisms. Even trees of the same species can be found in the grestest variety of sizes and shapes in different situations. Each tree as an individual organism has had a different history.

What a person sees, thinks, and asks when he looks at a tree depends upon his reason for looking. To the lumberman or forester the utility of a tree is obvious. The primary problem is to grow, harvest, and market it economically. Hikers and outdoor recreationists who enjoy the shade and serenity of the forest respond to different values. To them the problem is conservation or preservation. To the artist, seeing beauty of form and texture, the problem is to record his impressions. But the physiologist, once he has begun to study trees, is awed or even dismayed by their variability and complexity in spite of their superficial simplicity and familiarity. To him the problem is understanding.

There are many reasons why a tree cannot be simple physiologically. One of them is that, in the absence of a nervous system, each of its many organs can respond only to its own particular environment. That environment depends not only upon external physical factors, but also upon the substances and stimuli exchanged between organs. In a sense, a tree is a society of organs, each organ largely dependent upon the whole—not entirely subservient to it, but also influencing it. There is no strong central authority. There is dominance by virtue of position and suppression of the disadvantaged. In response to advantages and opportunities afforded by their position, some tissues or organs may become functionally specialized and thereby more dependent upon tissues and organs performing other functions. Indeed, it is this kind of interaction which allows the communal organism to survive and to compete with others.

A tree is a much-branched organism. It has a vast surface area both above and below the ground. Unlike higher animals it has no system by which oxygen-supplying or carbon-dioxide-removing organelles can be carried to and from deep-seated tissues and organs. For respiratory gas exchange, the tree is largely dependent upon simple diffusion in response to gradients arising from its own activities. Consequently the tree is not really living, growing, or synthesizing throughout all its bulk, but only in root and shoot tips and in thin layers beneath the root and shoot bark. These highly vital living and growing masses or layers are the organism's meristems. Thus, the tree is a society of interdependent

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organs and bears within it, as do some other societies, a great mass of dead or senescent wood which lends support and stature, contributing little but a base to new growth and development.

The Tree, the Meristematic Cell, and the Environment

A forest tree is totally immersed in its environment, and as an individual organism it cannot migrate if conditions become unfavorable. Its leafy crown is interlaced with the atmosphere and exposed to various types of radiation. The buds, even those with thick and hairy scales, can give the meristems within them only slight protection against extremes of temperature. The root system, extensive but mostly unseen, permeates a large volume of soil. The root tips and the absorbing zones of the roots are in intimate contact with the soil and are very much a part of the soil-root complex or rhizosphere. There is no inner visceral region within which the organism's vital functions could proceed in security. The tree cannot successfully evade the external physical environment; it must cope with it.

A forest tree is also very much a part of its own environment. Each branch of its leafy crown is also a part of the environment of its neighbors. It shades the branches below it and may itself be shaded by those above it. Collectively the leaves and branches shade the soil, moderate the flow of the wind, and change the composition of the atmosphere. The tree, as a social community of aerial organs connected by vascular tissues with its interdependent community of roots, competes with similar societies for light and space. Their often-intermingled roots draw upon the same reservoir of soil-water and mineral nutrients. Thus, the trees of the forest, in part, make their own environment—both biotic and physical.

At the microscopic level, each meristem within the tree is surrounded by a physical and biochemical environment partly of its own making. This is because meristems are mostly surrounded by their own progeny which came into being under the influence of local and organism-level environmental conditions prevailing earlier. A brief review of conditions within the cambium will illustrate this point.

The vascular cambium is the most extensive of all meristems. As a thin layer beneath the bark, it sheaths the woody core of each trunk, branch, twig, and root almost to the very tip. This thin cambial layer is primarily an association of two morphological types of otherwise similar meristematic cells—fusiform initials (spindle shaped) and ray initials (cuboidal). The progeny of each initial cell lie in radially oriented files extending both inward into the wood and outward toward the bark. On the inner margins of the cambium lie those offspring of the fusiform initials which are differentiating into xylem cells. On its outer margin are those which are becoming phloem elements. The scattered, cuboidal ray initials likewise abut against their offspring of differentiating ray parenchyma cells. Except for possible lateral and longitudinal propagation of biophysical stimuli, and possible intracambium translocation of small amounts of biochemically active substances from distant apical meristems, all organic substrates and mineral nutrients used by the meristematic initials, and all stimuli they receive must come from or pass through their progeny.

The Meristem Concept

In spite of its great expanse and continuous topology, the cambium is not a dominating meristem. It can only increase the diameter of axes which already exist. Establishment of cambial activity in newly elongated root and shoot segments depends upon assumption of the cambial initial function by suitably located procambial cells derived from root and shoot apical meristems. It is the apical meristems which, by their variable activities in initiating new organs and tissues and in influencing the elongation of older axes, really determine growth and form.

Normally the tip of every branch is surmounted by a small dome-like mass of succulent cells, the shoot apical meristem. Likewise the tip of every root has within it a mass of potentially meristematic cells, the root apical meristem. These thousands of root and shoot apical meristems, however, are so small and the extensive cambial meristem so thin, that collectively all the meristems constitute a physically insignificant fraction of the total mass of the tree. The future of the tree depends, nonetheless, upon the activity of these meristems. Collectively the shoot apical meristems are the most active determiners of tree growth and form.

In terms of contemporary developmental biology, the meristem concept is old and well established. But

in the time scale of the whole history of biology the concept is a relatively recent one. In the early 19th century the cell was vaguely known but was not recognized as the basic structural unit of all plant parts. Nothing, of course, was known about the origin of cells. Understanding of tissue structure and cell origin was made possible by the development of the achromatic microscope during the early decades of the 1800's and of the precision microtome somewhat later. Anatomical and morphological studies enjoyed a heyday beginning in about 1830.

Schleiden, Schwann, Von Mohl, Nägeli, and Hofmeister established the cell as the building block of all tissues. They also advanced the concept of a single apical cell of very special attributes from which all other cells of the shoot or root could be derived by division. This "apical cell theory," though a great advance over ideas of spontaneous generation, was unfortunately an oversimplification except for mosses, ferns, and some other lower plants. The theory was nevertheless vigorously defended and was only gradually dislodged by proponents of Hanstein's histogen theory, first advanced in 1868.

The histogen theory proposed that shoot and root apical meristems consist of a central core of irregularly arranged cells covered by a variable number of mantle-like layers. It maintained that each layer, and the core, is derived from a distinct cell or small group of such cells (the histogens). But it went further to claim that a cell arising from a certain histogen was thereby predestined to develop into a component cell of the tissue characteristically derived from that histogen. It was this predestination aspect of the theory which evoked the most criticism and which led to its gradual demise. In 1924 when Schmidt published his still useful "tunica-corpus" theory, the botanical world was receptive.

A transition to modern concepts was already evident by the turn of the century. Formalism declined, and increasing emphasis was placed on accurate description without tortuous attempts to make observations fit preconceived patterns and theories.

The apical cell theory, the histogen theory, and to a lesser extent the tunica-corpus theory, were concerned with the lineages and destinies of individual cells. But after 1930 new interest in physiology and developmental morphology turned emphasis toward understanding how the various tissues and organs of the plant axis are developed from the relatively undifferentiated cells of the meristem. The location of the ultimate source of cells in terms of lineages became an academic question. (For literature references on the historical development of the meristem concept, see *3, 7.*)[1]

With rising interest in the physiology underlying developmental anatomy, there gradually arose a concept of cyto-histological zonation within the dome-like apical meristem. This idea depends upon the demonstrable existence within the meristem of zones distinguishable by cell size and degree of vacuolation, relative nuclear volume, histological and histochemical staining, frequency of division, relative cell wall thickness, and orientation of planes of cell division. This concept came to fruition in 1938 in Foster's (*4*) application of cyto-histological zonation to the interpretation of the shoot apex of *Ginkgo*. Since then, much work has been done and the opinions expressed and the terminologies used have been quite variable. Although only a minority of woody species has yet been studied in detail, it is safe to say that details of zonation vary between species, between individuals of a species, and probably also vary during different phases of the growth cycle in the apex (*3, 6, 7*). This is compatible with the idea that cyto-histological zonation is a clue to the differing physiological states and processes prevailing within regions of a meristem at some moment in time. It speaks against an inherited pattern unresponsive to, and not indicative of, actual local environmental conditions.

The important physiological questions about the shoot apices are much the same for all higher plants. What controls the plane of orientation of cell division, or its frequency? If cells in different regions behave differently because of their location, what are the cell-level environmental factors which determine that behavior? What controls the initiation of primordia and determines the mode of their subsequent development? Is it true that, within the broad range of possibilities allowed by the genetics of the organism, cells behave as they do because they are where they are? Is the local environment in the morphogenic "driver's seat?"

As the experimentalist finds it, the shoot apical

[1] Italic numbers in parentheses refer to "Literature Cited", p. 10.

meristem is a microscopically visible and reasonably accessible dome-like mound of cells capable of growth and division. The progeny of these cells, by the various processes of development, become new lateral organs or new axial tissues. Both whole-plant physiology and molecular biology are of an inappropriate scale for the study of apical meristems. A tissue or organ level approach seems to be most effective for studying questions about the shoot apical meristem.

The Burden of History

THE shoot apical meristem is almost always located within a bud, or a bud-like structure of some type. Like the cambium, it is almost entirely surrounded by the products of its earlier activities. A bud develops from the outside in because all its parts are derived from the meristem inside. The oldest structures are the outside scales. Typically the apical meristem has as its most intimate covering the youngest primordial leaves or the youngest scales. The numbers of primordia present, their type of development, and the kinds of metabolites, vitamins, and hormones within them at any time will have been determined by the combined influences of local internal (largely biochemical), and organism-level (largely physical) environments prevailing in the past.

In a sense, the influence of the past is always in evidence. Substances synthesized in response to yesterday's conditions, be they simple metabolites or potent growth regulators, are present today as a part of the cell environment and of the system responding to today's conditions. Tissues differentiated or modified in response to last month's drought, cold, or long photoperiods are a part of today's environment. Thus, we cannot expect that similar plants with different histories will immediately give the same response to today's experimental environment. The present form, structure, and biochemistry of a tree are the result of many small developmental decisions made in the past. But these present attributes are a part of the local environment of today's meristems in all parts of the tree and will influence the behavior and morphogenesis of today and tomorrow.

If we are cognizant of the many aspects and levels of environmental effects upon tree growth, it is obvious that a study of growth and development of woody plants must pay close attention to past and present environmental conditions. First, we must thoroughly acquaint ourselves with the fundamental patterns of development under an arbitrary but reproducible environmental regimen. We must carry into that regimen a minimal body of influence of the past (the burden of history) and then we must learn how the fundamental patterns are varied by deviations from the arbitrary standard conditions.

Continuous Embryogeny

A study of higher plant development reveals a large and striking difference between plant and animal embryogeny. In the plant there is no well-defined period of gestation under controlled conditions during which the future organization and form of the organism are determined. There is no gastrulation followed by rapid development of an embryo with complex systems of internal organs. There is instead a simple right-side-out embryo and a long-term retention of the capacity for cell division. There is continuing embryogeny, first in the cells at opposite ends of the embryo, then in root and shoot apical meristems arising from them, and later in the cambia and in all root and shoot tips of the seedling, the sapling, and the tree. Of course, as the embryo grows into a tree, the one epicotyl meristem and the one radicle meristem each becomes a community of many meristems separated by stem and root tissues, but this decentralization does not change the fact of continuous embryogeny.

It is likely that many, perhaps all, new cells are totipotent. They probably contain all the genetic information necessary for the development of the entire organism and the expression of all its attributes. But there could be no organs and no complex organisms if each cell were allowed unbridled freedom of self-expression. The new cells left behind by an advancing meristem are at first presumably uncommitted to any particular type of development except for the limitations imposed by their genetic potential and their position within the organism. Although the predestination feature of Hanstein's histogen theory is not an acceptable explanation, most juvenile cells soon do become committed to a particular line of functional and structural specialization. This occurs under the combined influences

of the local physical environment and of substances diffusing into the juvenile cells from the meristem proper and from the already mostly differentiated, more distal, older tissues.

Thus, although a few of the progeny of meristematic initial cells functionally replace their progenitors, most of them become components of organs and structural tissues. Except during the depths of seasonal dormancy, the continuous embryogeny of a tree's meristems thus results in almost continuous reproduction at the cellular, the tissue, and the organ level.

But reproduction at the organ and tissue level cannot by itself insure survival of the species. There must also be a reliable procedure for reproducing the whole organism. The potential totipotency of some of the relatively undifferentiated cells in the cambium and neighboring tissues, coupled with the continuous embryogeny of the apical meristems, makes possible organism-level reproduction by fragmentation and regeneration of missing parts. Thus, stem cuttings can produce roots and, conversely in some species, fragments of roots can organize shoot buds. This kind of "vegetative" reproduction gives rise to clones of organisms—all of which, theoretically, have an identical genetic constitution.

Vegetative reproduction is useful to the forester and horticulturist and seems also to serve some plants very well in nature, but exclusively vegetative reproduction does not allow a species to evolve or to be improved by selective breeding. We known, of course, that trees are also capable of so-called sexual reproduction, and that most species produce "flowers" and seeds containing embroys which are not genetically identical. What we do not know is the exact *when*, the *how*, or the *why* and *why not* of the developmental decision culminating in the appearance of flowers and the very interesting events which occur within them.

From Asexual to Sexual: Sometime Flower Power

WE often designate tree flowers or their parts as male or female. In dioescious species we speak of individual trees as being male or female, and such they seem to be. Yet botany textbooks tell us that the tree is a sporophyte—an asexual organism. This apparent paradox arises because sexual reproduction in trees, as in other higher plants, is more involved than one might first suppose.

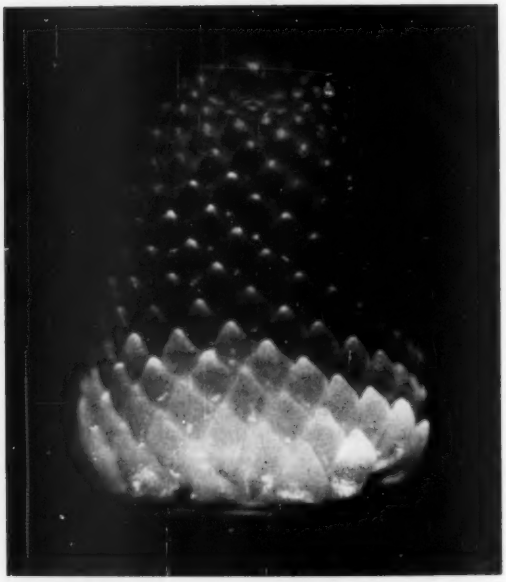
Before the nuclear and chromosomal processes which are the essence of sexual reproduction can occur, the structures that we call flowers must arise from asexual tissues. In forest tree species, flowering does not commonly occur in young individuals. In older ones it is still rather irregular from season to season and never involves all the buds. By inference, floral development is possible only in some apices even when the prevailing internal physiological conditions and ambient environmental factors are "permissive" (*8*). In nature it is probably only those apices already potentiated by a certain environmental history that can be "induced" by contemporary conditions to follow a morphogenic program divergent from the usual vegetative one. "Floral induction" is a poorly defined event with respect to both time and location, but its decisive phases must of necessity occur in or near the apical meristems from which the new organs arise and begin their differentiation.

The experimental investigation of floral induction in mature trees is discouragingly difficult. The culture of shoot apical meristems, however, makes the experimental study of shoot morphogenesis feasible and there is no reason why such study should be limited to vegetative development. It is reasonable to expect that eventually it will be possible to learn how, by chemical and environmental manipulation, meristems in culture can be made to initiate primordia that develop into floral parts. This is one of the more distant goals of our research.

At this point in our discussion a brief review of the essential morphogenic aspects of flowering and sexual reproduction in trees may be helpful in indicating the type of poorly known terrain that must be explored before a reliable route to that goal can be posted.

In the early stages of floral development, organ primordia homologous with those which otherwise develop into leaves or lateral branches develop instead into specialized organs—megasporophylls and microsporophylls in gymnosperms, or carpels and stamens in angiosperms. All of these are potentially spore-bearing structures. They are already morphologically and physiologically different from foliar organs of a similar age before any sporogenous cells or tissues appear.

In accord with the "morphogenic program" invoked by floral induction, but probably still dependent upon favorable local microenvironmental conditions, small groups of



Lateral view of a typical embryonic shoot from a dormant vegetative bud of Norway spruce. Note the dome-like apical meristem at the top.

cells (or single cells) within each sporophyll, carpel, or stamen may diverge from the developmental mode of their peers. These cells, with large, prominent nuclei, gradually become larger still and quite different from their neighbors in morphology and ontogeny. They are archesporial cells. When they divide they go beyond mere mitosis to meiosis (reduction division) and produce haploid spores. Strictly speaking these spores are still asexual, but they are nonetheless of two types: Megaspores, which develop within megasporophylls or within carpels; and microspores, which develop within microsporophylls or within stamens. Megaspores "germinate" to produce female gametophytes. Microspores (pollen grains) "germinate" to produce male gametophytes. The haploid gametophytes, which are generally vestigial and near microscopic, are the "alternate generation," the sexual generation of classical botany.

The gametophytes, though mostly hidden within the floral parts of the asexual sporophyte "parent," are theoretically separate organisms. Actually they are totally dependent upon the parental sporophyte tissue for the necessities of life. With no persistent meristems and no vascular tissues, the gametophytes have no future as individuals. Their salvation lies in their ability to differentiate male (the sperm nuclei of pollen) or female (archegonia and egg cells) gametes. If the male finally merges with the female, in spite of indifferent (wind, gravity) or self-fulfilling, insect) transport agents, pollination and fertilization have occurred.

The union of a sperm with an egg (syngamy) marks the beginning of a new diploid and asexual sporophyte, first as a zygote within the womb-like female gametophyte, then as an embryo with newly organized meristems within the maturing seed. Differentiation and maturation of cells generated by these meristems and their progeny over the years gradually produced a mature tree capable of divergent development in localized meristematic areas, which will again produce archesporial cells, spores, and gametes.

The induction of flowering as a problem in developmental physiology has been the focus of much research in recent years. The problem is one of controlling or understanding differential activities of apical meristems and differential development of initially similar primordia. Quite obviously the early critical stages of floral induction must occur in tissues which are asexual, vegetative, and meristematic. Consequently, the answers to the questions of the rationale of flowering in trees are probably not to be found in studies of sporogenesis, or of the origin of gametes. These processes can occur only after the critical developmental decision to diverge from the vegetative norm has already been made. It is more likely that eventual understanding of, and control over, floral initiation can be attained via research leading to understanding of the control of morphogenesis at the vegetative shoot apex.

In retrospect, in sexual, organism-level reproduction, especially in gymnosperms, the first steps are not very different from those leading merely to additional sporophyte organs. For this reason we do not yet know what the first steps really are. Nevertheless, we cannot proceed with experimental work without some conceptual framework about which to orient our thoughts. In this sense it is helpful to postulate that when all of the mostly unknown systems involved in determination of development are in a "permissive" condition (*8*) and certain preliminary morphological changes have already occurred, some cells in some buds or shoot tips are able to differentiate in a direction not open to most other cells. These can become archesporial cells and follow a program eventually leading to gametes. The early floral organs in which archesporial cells arise are already different in form from vegetative organs. We can only assume that the internal biochemical and biophysical environment is also different and that archesporial cell development is a response to such different conditions. Viewed in this way the problem of floral induction or initiation is ancillary to the overall problem of control of growth and morphogenesis near the shoot apical meristem.

The Experimentalist's Problem

ALONG with other biologists, tree physiologists rejoice in the triumphs of molecular biology. It is indeed euphoric to know that all the information needed to direct the development of a plant through its life cycle is encoded in the order of bases of the genetic DNA, and that this information is transcribed onto messenger RNA, which can, with the cooperation of ribosomes and transfer RNA, direct the synthesis of specific enzymatic and other proteins. In this way the content of genetic information sets limits as to what kinds of enzymes can and cannot be synthesized and indirectly determines what kinds of developmental "options" are theoretically possible for an individual plant.

Actually, of course, one can hardly believe that the mindless plant has any choice or "options" at all. We have all heard of "programed development." But what actually does the term mean? The plant does not contain a miniature computer reading instructions from a magnetic tape. Yet, there must be some control over the release (derepression) of various segments (operons) of the genetic information, a large fraction of which is repressed at all times. In any species that has reproduced and evolved through the ages, this release cannot be haphazard, but must enable the various cell communities of the organism to respond to the exigencies of their particular environments and the whole organism to participate in the ecological struggle of existence. The photomorphogenic pigment system known as "phytochrome" is an example of a plant receptor able to detect and induce responses to changes in light quality or photoperiod lengths. In the end, stimuli received from the various levels of the environment must control the release of genetic information and probably also the selective implementation of that which has been released. Are there any other possibilities?

What we need to know now is how the various past and present environmental influences control "derepression" of genetic information. And further, is "programed" development anything more than the limitation and prejudication of possibilities under the present environment by the lingering influences of past developmental events or processes, which in turn were made under similar restraints? We also need more fleshy ideas on just how the presence or absence of certain enzymes, or their relative activity, can result in the development of structures, such as leaves, having a highly sepecific and characteristic shape. Where and what manner of substances are the morphogens of morphogenesis?

Much has been written of hormones and growth regulators. As organic molecules themselves arising from enzymatically catalyzed syntheses, and susceptible to similarly catalyzed degradations, they can be important messengers and cordinators, but hardly the prime movers of development. At the cell and tissue level, hormone-like "growth regulators" are part of the biochemical environment. But hormone concentrations or activities may themselves respond to changes in other parameters. Nor can we be sure that a differentiating cell in a changing environment cannot change its mode of response to a hormone. The experimentalist must accept these intricacies and by patient analysis seek to clarify and to understand.

The experimentalist can usually get a clean and distinct answer only if he asks a single well-defined question by means of a simple well-designed experiment. He cannot at the experimental level at once be concerned with all aspects of development, or with all the tissues and organs of the plant. Both the environmental and the living and responding system must be simplified as much as possible. It is in this sense that the culture of meristems under controlled conditions offers real hope for progress.

Essentially the study of development and morphogenesis in the tree is the study of growth and differentiation near the meristems of the shoot apex, the root apex, and the vascular cambium. This is true because it is there that new cells originate and differentiation or entrainment of new and uncommitted cells begins. It is also there that new tissues and organs originate. The tissues near the meristem are perpetually young, pliable in form, and responsive to present conditions though they are inevitably products of the past. Theoretically at least, if the meristem can be isolated from the older tissue, the influence of the past is reduced and the morphogenic influence of present conditions should be more clearly evident in the new organs and tissues formed in culture. This idea, of course, is not entirely new (*1, 5, 11*), but culture efforts have been mostly confined to herbaceous plants.

When the late P. R. White was still a young man he decided (*10*) that, in spite of earlier failures,

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great contributions to plant science could be made by the successful culture of plant tissues *in vitro*. He also decided that one should begin with meristematic tissues. And so he began what was to be a lifetime of work on the problems of plant tissue culture. White's work inspired others and as a result it has been possible to grow tissues from a variety of sources into masses of callus and sometimes into plantlets (*2, 12*). But the culture of organized meristems for the purpose of studying the control of their growth and development has lagged. Little has been learned about the conditions necessary to promote controlled development of isolated primordial organs. The lag has been especially serious with woody plants, and work with meristems of conifers has been very meager indeed.

Once it has been decided to attempt the culture of meristematic tissue, the extent of injury during excision must be considered. Tissues that are deeply buried (cambium, procambial strands, etc.) require excision on six faces. Root or shoot apical meristems can be excised with only one cut. Of these, the shoot apical meristem is more interesting because it directly produces primordia which can become leaves, scales, or lateral branches, and it is potentially autotrophic. Furthermore, though small, it is readily accessible and quite free of micro-organisms. In contrast, the root apical meristem does not directly produce lateral organs, and is covered by an inconvenient cap usually bearing a rich microflora.

Both its intrinsic importance and the added difficulties of working with other meristems make the shoot apical meristem the logical choice of the experimentalist. Some injury during excision is, of course, inevitable and must be accepted in order to gain the advantage of a small, well-defined living system.

Culturing Meristems

IN theory, the culture of shoot apical meristems is quite simple. The dome-like meristem of, for example, Norway spruce is about 0.3 mm. in diameter and somewhat less in height. To bring it into culture one must, while maintaining sterility, expose it to view, cut it off with a microtool causing as little injury as possible, and transfer it to a suitable nutrient medium. The culture must then be kept sterile and be nurtured under a controlled environment while its growth response to various treatments is periodically observed.

The practical problems to be overcome in culturing meristems and establishing a set of standard procedures are legion. At the Forest Physiology Laboratory in Beltsville, Md., we have been contending with these problems for several years. The technical details of the methods we developed are being published elsewhere (*9*).

What is the goal of our meristem culture efforts? It is not merely to accomplish the feat of keeping bits of tissue alive and growing. It is to learn how their growth and development are, or can be, controlled by manipulation of the biochemical and physical environment. Because of this more distant objective, the formulation of the basal "point of departure" culture medium becomes a problem in itself. Mere adequacy is insufficient. The basal medium should contain no unknown or unnecessary ingredients and should allow survival and minimal or moderate rather than maximal growth. If we assume a nonlimiting physical environment, growth should at all times be limited by deficiency of some essential substance rather than by the presence of an inhibitory compound.

Once a basal medium has been designed, it is possible to test the effects, in lifting the growth limitation, of known substances added to it. These may be metabolites known or suspected to be normally supplied to the meristem by older tissues; or they may be "growth regulators," the mode and locus of action of which is not yet known. In this way we can begin to learn how, under a given set of physical environment parameters, the growth and development of the meristem and the primordia arising from it are affected by known changes in the biochemical environment. Likewise the biochemical environment can be held constant while physical parameters are being varied.

We have already cultured about 4,000 shoot apical meristems excised from seedlings of Norway spruce. These dome-like explants, initially including no primordia and having a fresh weight of about 15 micrograms, will survive and make good growth on a medium consisting of water, mineral salts, sucrose, urea, inositol, thiamin, and purified agar. No coconut milk, yeast extract, or hormonal preparations are needed. On this medium an initially smooth-surfaced dome will initiate as many as 10 new primordia during its first week in culture. Initiation and growth of these primordia can be observed and can be photographed under the micro-

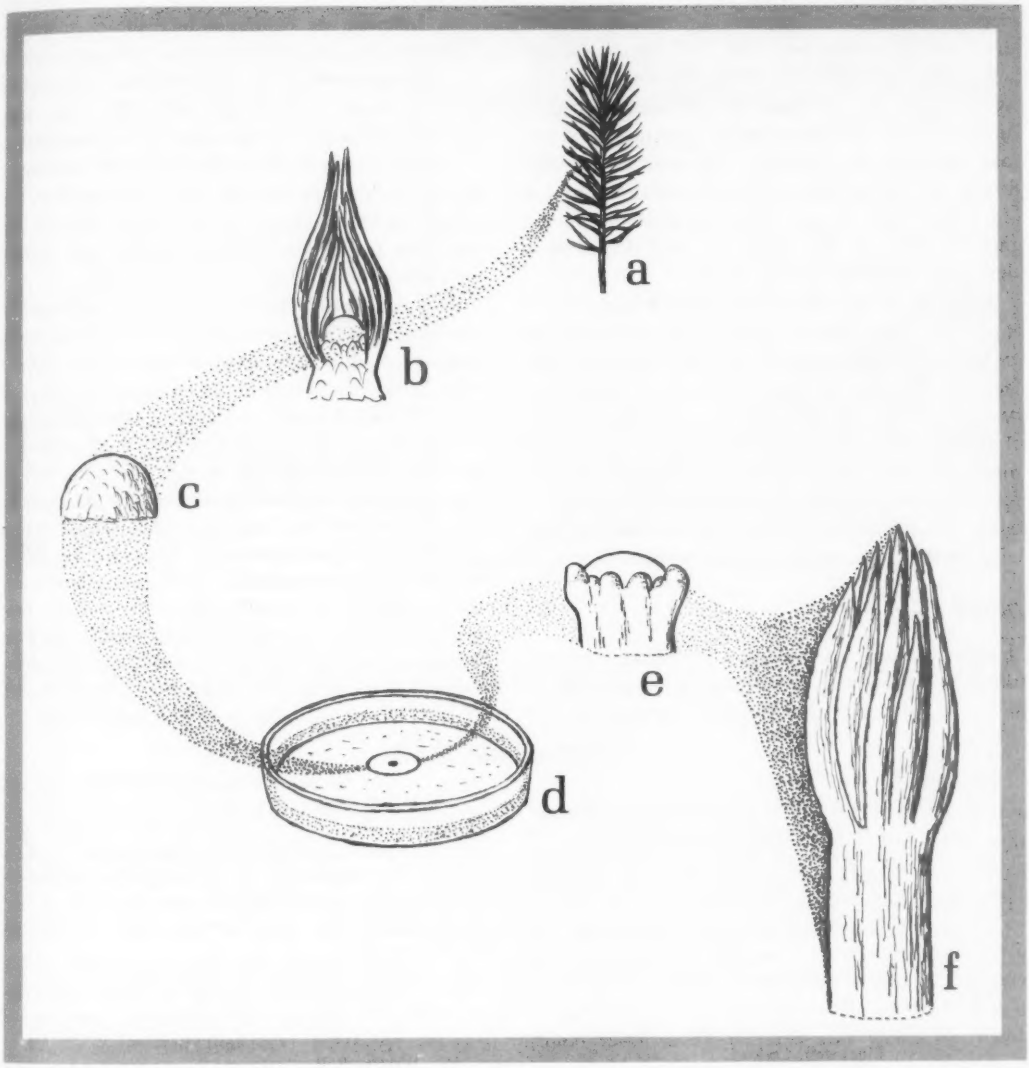

FIGURE 1.—The rationale of apical meristem culture. Every growing shoot tip or living bud contains within it an apical meristem from which all new leaves, scales, and buds arise. The activity of this meristem, within the range of its genetic potential, is presumably jointly controlled by the external physical environment and the intraorganism physiological and biochemical environment. The latter, though dynamic, is always largely predetermined by the processes and events of the past. Culturing the isolated meristem reduces the influence of the past and allows study of the control of growth and morphogenesis.

The shoot tip of a growing 4-month-old Norway spruce seedling consists of a soft stem bearing short, succulent needles, (a). It is surmounted by a semitransparent, dome-like apical meristem which is exposed after most needles have been cut away (b). The apical dome can carefully be cut off, leaving behind its "burden of history," and transferred (c) to a small disk of filter membrane lying on an agar-based nutrient medium. The explant at first appears only as a featureless speck (d), but during its first week in culture it grows taller and the primordia of new leaves appear (e). After 3 weeks of growth in a defined environment the culture is green and the meristem is again hidden by a tuft of small leaves (f). Dry weight commonly increases 20- to 25-fold during 3 weeks of culture on a suitable medium. Thus, many aspects of growth and development, the investigation of which is not favored by whole-plant techniques, become amenable to study.

scope. A freshly excised dome is almost colorless, but the growing culture becomes quite green. During a 3-week period it will typically show a large dry-weight increase—as much as 30-fold. Thereafter further growth and development becomes slow, but may continue for months. The reasons for this decline are not yet known. Growth and development of cultures has always been morphologically organized. None of the cultured apical domes have developed any basal callus tissue.

Thus, the culture of isolated apical domes of trees is possible. The study of control over the initiation, growth, and differentiation of new organs is now feasible. The chief obstacle in doing the many experiments which should be done is the great amount of skilled labor needed to excise and handle the meristems. The adaptation of microanalytical techniques to allow biochemical analysis of fractional milligram amounts of cultured tissue is still a problem, but progress is being made.

Distant Vistas

THE cultured apical meristem cannot yet be grown into a dormant embryonic shoot with an apical dome at its tip, although this happens naturally in the bud. Likewise we cannot induce the development of a primordial strobilus in culture. We cannot cause a single primordium to develop into a sporophyll and produce archesporial cells. However, such potential achievements no longer seem unattainable.

Once a basic core of understanding of the control of apical development has been put together, the design of experiments can be more efficient, the arbitrary component will be smaller, and further progress is likely to become autocatalytic.

It is not possible to say exactly how information deriving from the experimental culture of meristems may eventually affect practical forestry and agriculture. There must first be an intermediate state of research with the intent of applying basic biological knowledge to the solution of practical problems. However, it seems almost obvious that once we can control growth and development of the apical meristem in culture, new insight will be possible into such practical problems as the control of epicormic branching, the induction or inhibition of flowering, the regulation of apical dominance, and the prolongation of the juvenile phase of growth. It is by this route that the culture of shoot apical meristems can promote our ability to produce larger volumes of higher quality timber from our forest lands.

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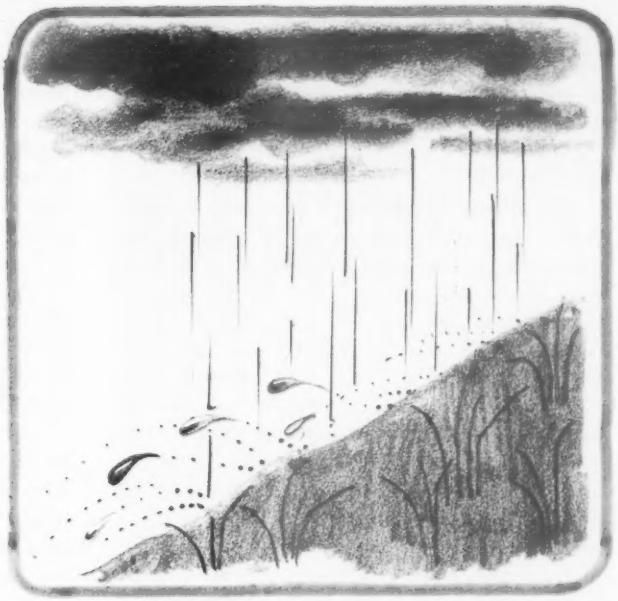

WATER REPELLENT SOILS:

A WORLDWIDE CONCERN IN MANAGEMENT OF SOIL AND VEGETATION

LEONARD F. DEBANO

A novel soil phenomenon—dusty patches on the ground following heavy rains—has long been a subject of curiosity to agronomists. But what causes this water-repellent condition has kept them guessing for at least 25 years. Soil scientist now realize that some soils are nonwettable. In fact, they repel water much the same as a duck's feathers do.

Water-repellent soils are not an isolated curiosity. They are found in many parts of the world—from Australia to the United States. And they are no longer of concern only to soil scientists. Water-repellent soils have widespread implications for land management. They can be a serious problem on steep slopes, where they reduce infiltration of rainwater and cause erosion. But they may also be an asset, for example, in arid regions, where soils might be artificially waterproofed to obtain more water.

Hydrophobic substances in soils are responsible for water repellency, but so far, their identity has not been established. But this much is known. The material can be naturally occurring organic substances, or it can be artificial compounds applied to produce water repellency. Soils having extremely lower permeabilities (e.g., clay and hardpans) are not considered water-repellent in the sense used in this paper. And limited pore space is not considered a problem in water-repellent soils because many of them have sandy textures and would be highly permeable if water could penetrate.

This paper considers the importance of water repellency in land management, factors producing water repellency and the effects on moisture movement, problems and benefits of water repellency, and remedial treatments designed to increase soil wettability.

IMPORTANCE OF WATER REPELLENCY

WATER repellency affects both the stability and the usability of soils. Severe water repellency can

alter soil-moisture relationships and severely impair the growth of vegetation. Before plants can be successfully grown in these problem areas, special management techniques must be used.

Soil Management

Australia.—Water-repellent soils with a sandy texture cover thousands of square miles in Victoria, South Australia, and Western Australia. The soils here support a grass cover on 25 inches or less of rainfall annually. The pastures look patchy where well grassed areas alternate with bare areas over small distances. A close examination of these patchy areas shows that moisture penetrates only the grass areas. The intervening bare areas are dry. Even after rainstorms, these areas remain dry because the soil is extremely water repellent. The irregular wetting causes uneven germination and a patchy, less productive, pasture.

California.—Water repellency is a problem in the steep, unstable foothills that lie above highly populated areas in southern California. The foothill areas are extremely erodible after fire. Fires are common during the long dry seasons after the dense chaparral cover has become tinder dry. On the average a given area burns once every 30 years. The high erosion rate after fire has been shown to be due, in part, to a water-repellent layer that is formed during the fire.

Erosion and debris from these foothills are a constant threat to the lowerlying communities. Flood damage has been reduced by constructing dams and reservoirs in the mouths of many canyons emptying into these populated areas. Maintaining the storage capacity of the flood control reservoirs filled by repeated erosion is expensive because the debris must be removed and transported away from the site.

Vegetation Management

Turf management.—The effect of water repellency on vegetation management is illustrated by a phenomenon commonly called "fairy rings." In otherwise healthy turfs and lawns, unsightly, circular-shaped bare areas have been observed for many years. Early folklore attributed these bare areas to the paths of dancing fairies, places where the devil churned his butter, the habitat of enormous toads with bulging eyes, and places where treasures were buried. Notwithstanding mythology, the bare spots are actually places where dense fungal mycelia proliferate the soil. These mycelia stimulate grass growth for a short time. The rapid growth of grass quickly exhausts the soil moisture, and once the soil is dry, the fungal growth prevents it from rewetting; that is, it becomes water repellent. An intense drought will kill the grasses, leaving the areas bare and subject to an invasion by weeds.

"Fairy rings" are a serious problem to the turf grass industry because a uniform velvety green grass cover is esthetically desirable. Golfers find the problem particularly annoying because of their need for smooth, unbroken cover in putting.

Peat bogs and high organic soils.—Irreversible drying can be a problem in soils containing large amounts of organic matter. Nurserymen often find it hard to rewet soils used in plant beds after the soils have been allowed to dry. Such soils often have large amounts of peat and other organic matter. There is usually no problem, however, if plant beds are kept moist.

The general subsidence of peat bogs partly involves irreversible drying. A first step in reclaiming a peat bog is to lower the water table. But if the water table is lowered too far, capillary water cannot keep the surface moist. The surface drys out and becomes difficult to rewet. Therefore, any subsidence caused by draining cannot be restored by subsequent flooding. Both subsidence and irreversible drying will generally reduce the productivity of these areas.

Plant diseases.—Water repellency is responsible, indirectly, for a disease called "citrus decline." During droughts in Florida, older trees in citrus groves sometimes drop their fruit—even after they have been irrigated. The irrigation water wets only a small part of the soil in the root zone beneath the branches. Organic material in the surface horizon has been found to be resistant to wetting. Therefore, the surface layer under the tree crown acts like a roof, shedding water to the wettable soil beyond the leaf drop area where it is less available to tree roots.

EFFECTS OF WATER REPELLENCY ON MOISTURE MOVEMENT

General Nature of Wetting

WATER quickly penetrates a dry wettable soil because of a strong attraction between it and the soil particles. The water films and the soil particles

attract each other at the point where air, water, and soil meet. This attraction can easily be illustrated if the soil is visualized as a bundle of small glass capillary tubes. When the ends of the tubes are immersed in water, the water will rise because of an attraction between the water molecules and the wall of the tube. Surface tension at the meniscus moves the water not in contact with the walls. The attraction between the capillary tube wall and water can be considered somewhat analogous to that between the water molecules and the soil particle surfaces in a more complex soil system.

When water moves up a capillary tube, a definite and measurable angle is produced between the meniscus and the wall. The capillary rise equation defines how high water rises in the tube:

$$h = \frac{2\gamma}{r\rho g} \cos\theta \qquad (1)$$

in which

h = height of rise
γ = surface tension
r = radius of the capillary
ρ = density of the liquid
g = gravitation term
θ = angle between the water meniscus and the wall.

If the capillary wall is made of clean glass, the angle (θ) is small and assumed to be zero. If the angle is zero, the height of rise is directly related to the surface tension and is inversely related to the tube radius; that is, the smaller the radius of the tube the higher the capillary rise.

Coating the walls of the capillary tube with hydrophobic substances (e.g., waxes and oils) can reduce the attraction between water and the glass walls. The water then will not rise as high as in a clean tube. Wetting angles calculated for the treated capillary tube are considerably greater than zero—sometimes exceeding 90°. Such angles can also be obtained with other liquids. For example, in an ordinary mercury thermometer, the angle exceeds 90° and the meniscus shows a so-called capillary depression. Mercury will not flow through the glass tube until a positive head greater than the capillary depression is applied. In soils, the common liquid present is water, and the wetting angle is determined primarily by the wettability of the particle surfaces.

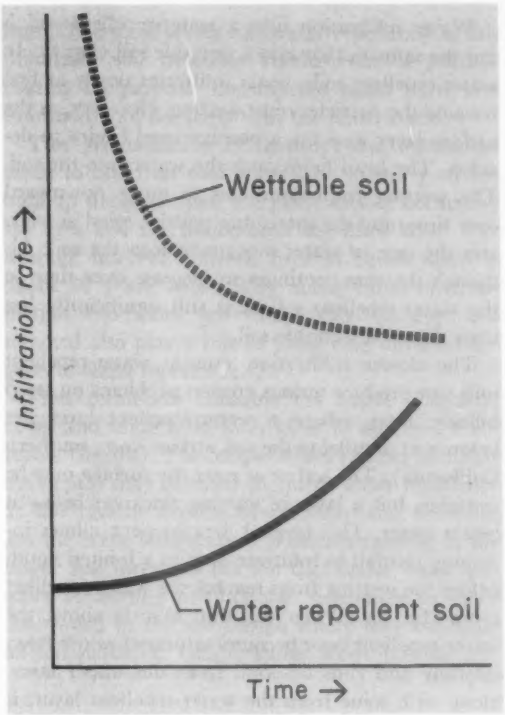

FIGURE 1.—Typical infiltration curves for water repellent and wettable soils.

The concept of a wetting angle provides a useful method for quantifying soil wettability. For example, the capillary rise equation (1) has been used to calculate a quantity known as the apparent liquid-solid contact angle. This angle increases as the water repellency in a soil increases. Angles up to and above 90° have been reported for soils that are highly water repellent.

Infiltration

WATER infiltrates rapidly into a dry wettable soil. The initial intake is high and decreases exponentially over time (fig. 1). At first, the adsorptive forces of the soil particles can draw water quickly into the soil. At later infiltration times, water applied at the surface must move through a nearly saturated soil layer before reaching the wetting front. The rate water can be transported through this saturated zone above the wetting front controls the infiltration rate.

Water infiltration into a water-repellent soil is not the same as that into a wettable soil (fig. 1). In water-repellent soils, water infiltrates slowly at first because the particles resist wetting. However, as the surface layer wets up, a positive head begins to develop. The head helps push the water into the soil. The wetting front continues to move downward over time, and the increasing positive head accelerates the rate of water movement into the soil. Although the rate continues to increase over time in the water-repellent soil, it is still significantly less than that in a wettable soil.

The slower infiltration rate in water-repellent soils can produce serious erosion problems on steep hillside areas, where a water-repellent layer lies below and parallel to the soil surface (e.g., southern California). The soil at or near the surface may be wettable, but a layer of varying thickness below it repels water. This layered arrangement allows incoming rainfall to infiltrate only to a limited depth before the wetting front reaches the water-repellent layer (fig. 2). When the thin mantle above the water-repellent layer becomes saturated, water flows laterally and runs off. Soil from this upper layer, along with some from the water-repellent layer, is carried away by surface runoff and is an important source of debris from freshly burned foothill areas.

Evaporation

HYDROPHOBIC substances reduce evaporation from soils and sands. Experiments have shown that evaporation losses may be 15 to 35 percent less from water-repellent soils than from similar textured wettable materials.

Less water evaporates from water-repellent soils for at least two reasons. First, the hydrophobic particle surfaces throughout the soil mass do not allow water to rise readily from the deeper soil layers to the surface. Second, a thin layer at the surface dries out rapidly, forming a "dry mulch" layer. This dry layer reduces the transfer of water from the underlying soil into the atmosphere. Water moves through this dry soil barrier very slowly by gaseous diffusion.

Lower evaporation rates from water-repellent soils may have important ecological implications. Plant species that can perpetuate themselves in areas having hydrophobic soils would have a competitive advantage over other invading plants. These resident plant species may either have special mechanisms for establishing themselves in a water-repellent soil, or may create a water-repellent condition by growing there. In either case, invading species would have to germinate and establish themselves in a harsh droughty environment. Also, less evaporation would probably conserve water in the deeper soil layers and help deep-rooted indigenous plants to survive.

FACTORS AFFECTING WATER REPELLENCY

WATER-repellent soils are probably produced by a mixing of the soil particles with hydrophobic substances. Several biotic and edaphic factors affect the production of these hydrophobic substances and their subsequent attachment to the soil particles. Organic substances found in some plants can induce water repellency without being altered. However, the plant organic materials are often altered by micro-organisms or high temperatures during wildfires to produce a highly water-repellent soil. The degree of water repellency also partly depends upon the physical properties of the soil.

Micro-organisms

RESEARCHERS in Australia have reported that fungi can produce water repellency in sandy soils to depths of 1 foot or more. Microscopic exami-

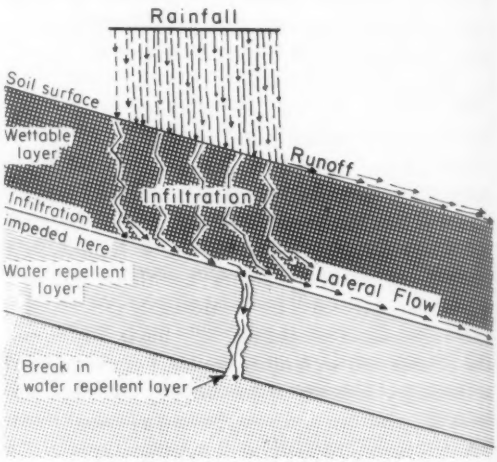

FIGURE 2.—Rain falling on the soil surface infiltrates rapidly until impeded by a water-repellent layer. After the wetting front encounters the water-repellent layer, infiltration is slowed up, and surface runoff and lateral flow commence. Surface runoff provides the moving force for soil erosion.

nation of the soils invariably shows a prolific growth of fungi. Soil samples collected under such higher fungi as toadstools or mushrooms also show water repellency—even in places where the sand is normally wettable. Basidiomycetes seem to be the dominant fungal type associated with many of the problem areas in these sandy soils.

Fire

In southern California, fire appears to play a crucial role in the formation of water-repellent soils. Chaparral brush species produce organic substances that can make soils water repellent. During the years between fires, leachate from the brush and decomposing plant parts accumulate in the upper part of the soil profile (fig. 3A). Water-repellent substances tend to concentrate in the upper part of the unburned soil profile immediately below the litter layer. The area corresponds roughly to the transition between the A_0 and A_1 horizons. Smaller amounts of the substances may be moved below this layer by infiltrating water. In addition, some substances may remain in the undecomposed plant litter. The most severe soil water repellency in this unburned soil probably results from a particle coating by partially decomposed plant parts and intermixing of the parts with the mineral soil.

The accumulation of hydrophobic substances tends to build up over time. The intensity of this buildup depends upon the plant species occupying the area and the thickness of the litter layer. The average interval between fires in brush areas is about 30 years. Most likely, many other environmental conditions governing litter buildup and removal also play a role in producing different degrees of water repellency.

Fires commonly consume the native chaparral cover and underlying litter layer in southern California (fig. 3B). The temperatures existing at different depths may intensify incipient water repellency at the various depths. More important, however, are the large temperature gradients existing in the upper few inches of the soil that cause vapor and gases containing hydrophobic substances to move downward in the soil profile where they condense on soil particles. Temperatures above the soil sur-

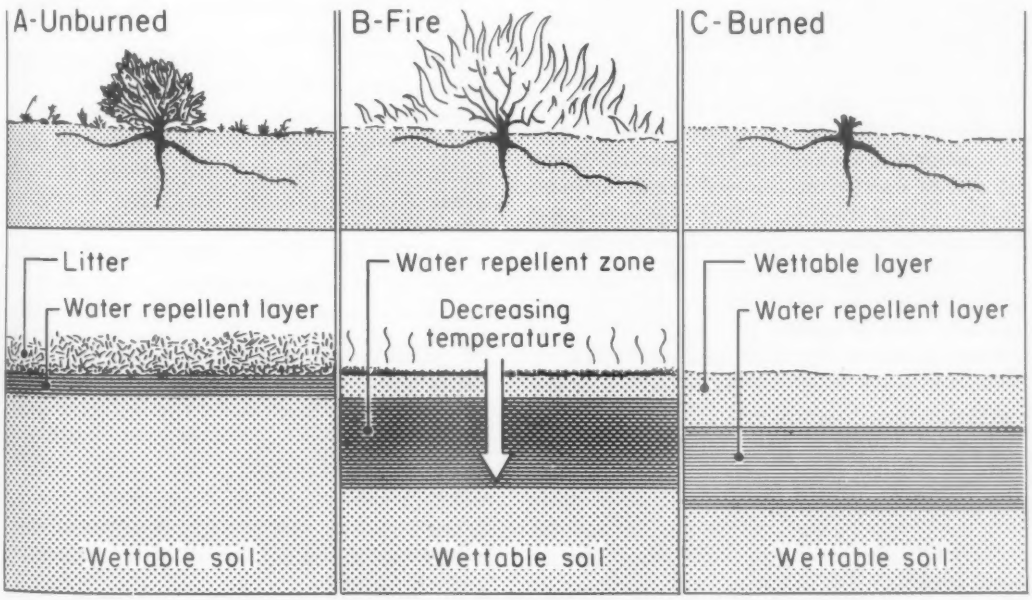

FIGURE 3.—Soil water repellency before, during, and after fire. (A) Before fire, hydrophobic substances accumulate in litter layer and mineral soil immediately beneath it. (B) Fire burns vegetation and litter layer, causing hydrophobic substances to move downward along temperature gradients. (C) After a fire, water-repellent layer located below and parallel to soil surface on burned area.

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face may soar as high as 2,000° F. Temperatures at the soil surface are less—temperatures of 1,400° F have been measured. Within the soil, the temperature drops rapidly because of the low heat conductivity of soil. At 2 inches below the soil surface, maximum temperatures of 350° to 550° F have been reported.

After a fire has swept through the area, the soil possesses a water-repellent layer (fig. 3C). The depth and thickness of the water-repellent layer depend on the intensity of fire and the nature and amount of vegetation litter present. If the surface temperatures are not high during a fire, the water repellency might be at or near the soil surface. If a hot fire has burned, water repellency could show up in deeper layers. Soil physical properties and water content of the soil also probably affect the movement of these hydrophobic substances downward in the profile.

Vegetation

THE type of vegetation may affect water repellency in several ways. First, plants probably have organic substances which can induce water repellency without being altered by micro-organisms. Second, vegetation may affect the type of microbial population present, and thereby cause different degrees of water repellency. For example, fungi decomposition products mentioned earlier seem to be an important source of hydrophobic substances in some sandy soils in Australia. If vegetation favors one type of micro-organism over another, it could also affect water repellency. Third, vegetation probably alters the effect fire has on water repellency. If large volumes of fuel are consumed during a fire, a more intense fire would be expected for longer durations than if smaller amounts of fuel were burned. An intense fire would probably produce a more severe water repellency than a less intense fire burning at lower temperatures.

Different degrees of water repellency are produced by different plant covers. In Australia, phalaris, mallee, heath, and pine induced water repellency in a decreasing order of intensity. The age of a particular pasture may also affect the degree of water repellency. For example, water repellency in soils planted to alfalfa increased as the age of the pasture increased; alfalfa pastures 11 years old were much more water repellent more than those 4 years old.

The degree of water repellency induced in sands by extracts from various chaparral brush species in southern California foothills also varied according to type of plants Chamise. (*Adenostoma fasciulatum*) produced the most severe water repellency. Decreasing water repellency by other species was in the following order: Mountain mahogany (*Cercocarpus betuloides*), scrub oak (*Quercus dumosa*), deer brush (*Ceanothus* sp.), and sugar bush (*Rhus ovata*).

Soil Properties

NUMEROUS soils physical properties probably influence the degree of water repellency in soils. If particle coating produces water repellency, then the amount and nature of the particle surfaces should be important. For a given amount of hydrophobic material, only so much surface could be coated. Thus, clay soils having large internal surface areas would be less completely coated than sandy soils having less surface area. Therefore, coarse textured soils would be expected to be more susceptible to water repellency than finer textured soils. Recent laboratory experiments support this expectation.

Other physical properties may also affect the degree of water repellency in a soil. The nature and strength of the charges on the surfaces of individual soil particles probably influence the manner in which hydrophobic organic materials are adsorbed. Therefore, a host of mineralogical properties could affect water repellency. Little is now known, however, about the role that these factors play.

BENEFICIAL APPLICATIONS OF WATER REPELLENCY

WATER repellency is not always an undesirable soil property. In some situations, it is desirable to have soils which repel water. Unfortunately water repellency does not occur naturally where it is most useful to man. Therefore, it becomes necessary to waterproof soils by artificial means. Practical reasons for waterproofing soils are: (1) to conserve water in arid regions, and (2) to improve the engineering properties of soils.

Water-repellent surfaces have been used to collect rainwater in arid regions. Normally the rain falling there is rapidly absorbed by the soil. This water is quickly lost by plant transpiration and surface

evaporation before it becomes available for other uses. But by waterproofing soil, the water runs off and can be stored in reservoirs where it can be used for livestock and other domestic purposes. Waterproofing is usually done with either artificial resins or thin plastic sheets. This water conserving technique is called "water harvesting."

Engineering properties of soils have also been improved by preventing the absorption of water. For example, the loadbearing capacity and strength of soils can sometimes be improved sufficiently by waterproofing so that soil materials can be substituted for crushed rock or aggregate in road bases and subbases. Loss of strength by freezing and thawing is also significantly reduced by artificial waterproofing materials. This technique appears to be useful in highway engineering.

DECREASING WATER REPELLENCY

IN many instances it is desirable to increase the wettability of a naturally occurring water-repellent soil; for example, an area where accelerated erosion is a problem or a pasture where productivity is low. Two general methods have been used to reduce water repellency: Mechanical and chemical.

Mechanical

IF water repellency is not severe, infiltration can be increased by ponding water on the soil. On level areas, this procedure can be used to make water penetrate a slightly water-repellent soil. The depth of ponding required to wet a soil depends on the degree of water repellency.

But if water cannot be ponded on the surface, infiltration can be improved by mechanically mixing the water-repellent soil with the underlying wettable soil. This mixing provides wettable passageways and allows water to penetrate. This technique can be used in areas where land-borne machinery can operate.

Chemical

LAND-borne machinery cannot be used for remedial treatments of water-repellent soils on steep terrain. Therefore, other methods of treatment are necessary. In such situations, wetting agents have been used to improve infiltration. Preliminary tests on small plots indicated that a nonionic wetting agent applied at about 6.6 gallons per acre will be effective. The improved infiltration not only reduces overland flow and subsequent erosion, but also provides better conditions for an annual grass to germinate and become established.

Although a wetting agent has reduced runoff and erosion from small plots, similar results have not been obtained on larger areas. For example, in the fall of 1968, researchers at the Pacific Southwest Station treated a 270-acre burned watershed with a wetting agent, but the treatment failed to reduce erosion during the winter rains. The method of application along with the weather conditions prevailing between the time of treatment and the first rains may have contributed to the results.

SUMMARY

MUCH has been learned about the problem of water-repellent soils within the last decade. Yet the implications of the problem are extremely diverse, and a number of information gaps offer exciting challenges for more intensive research.

- Although we know that the hydrophobic substances causing water repellency are organic compounds, identifying the chemical structure of these substances could: (1) Help us understand how the soil absorbs them, and (2) indicate which active groups of the molecule produce water repellency. This information could provide a basis for prescribing chemical remedial treatments such as wetting agents. For example, if certain chemical groups or linkages cause water repellency, then wetting agents could be synthesized to either combine with or mask portions of the molecule responsible for water repellency.
- Surveys of wildland areas indicate the presence of water-repellent soils in unburned plant communities. Water repellency could limit the invasion of new species into these areas, giving indigenous species a definite competitive advantage. Perhaps the ecological balance in a plant community could be manipulated by modifying the wettability of a soil with substances such as wetting agents.
- Water repellency appears to be a time-dependent physical property of the soil. For example, wetting resistance of a hydrophobic soil will de-

crease over time. This increasing wettability makes static measurements of water repellency inadequate. Instead, measurements should be based on the concept that the water repellency is a changing soil property.

Models describing water movement through hydrophobic soils must also contain parameters sensitive to different degrees of water repellency. The classic assumption that the wetting angle equals zero in models describing water movement is not valid for hydrophobic soils. The first step for developing models describing moisture flow would be to incorporate a wettability factor. This could be refined later by functionally relating wettability to variables such as time, moisture content, or some other pertinent physical properties which affect soil wettability.

- The most dramatic change which occurs when wetting agents are added to water is the reduction in surface tension. Surface tension can be decreased from 72 dynes/cm. to less than 30 dynes/cm. by a small amount of wetting agent. These agents probably improve wetting by their effect on the physical processes at the air-water-soil interface. Chemical reactions also undoubtedly occur between the wetting agent and the soil at the wetting front. However, the importance of the various physical and chemical processes produced by the wetting agent at the wetting front are not well known and need further study.
- Too little is known about the role of micro-organisms in producing water repellency. Although it has been established that micro-organisms do produce water-repellent soils in Australia, we do not know whether they affect fire-induced water repellency in brushland soils of southern California. Likewise, little is known about which micro-organisms may cause water repellency on unburned brushland areas, although some types are undoubtedly involved.

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HIGH-PROTEIN CORN RESEARCH IN MEXICO

REPORTS from the International Maize and Wheat Improvement Center[1] in Mexico indicate that commendable progress is being made on the development of commercial corn varieties with high-protein content. Work began at the Center in 1966 with opaque-2 and floury-2—the mutants that opened new prospects for improving the nutritive quality of corn. These two mutants have been crossed with various materials, and many collections in the germ plasm bank have been analyzed in a search for new mutants with high levels of lysine and tryptophan.

Highlights of some of these studies are as follows:

- On increasing the proportion of floury-2 in crosses with other materials, it has been found that both protein and the percentage of lysine and tryptophan are increased. The homozygous floury-2 has more protein that the homozygous normal. On the other hand, the homozygous opaque-2 has three times more lysine and tryptophan than the normal homozygous, but less protein.
- In respect to the percentage of protein and tryptophan, there is considerable variation in the effect of floury-2 on different pedigrees because of the fact that this gene is partially dominant in some of them.
- As the level of nitrogen fertilization applied to the corn planting is increased, the quantity of protein is improved but not the quality, because the percentage of tryptophan decreases as nitrogen fertilization is increased.
- The analysis of defatted endosperm has turned out to be more successful than the analysis of the whole kernel, because it is possible to obtain a high correlation between the values of tryptophan and lysine. In this way, through the rapid analysis of tryptophan, it is possible to obtain a better estimation of lysine content in a large number of samples.
- Although other promising mutants have not been found through the analyses of the numerous collections in the germ plasm bank, normal samples of the Mexican race Pepitilla have given some high tryptophan values.

THROUGH the analysis of complete kernels, self-pollinated ears of a cross of Mexican races with Illinois High Protein and with opaque-2 were studied. From the S_1 progeny the grain yields and protein production per hectare were estimated. The progenies with greatest protein per hectare were derived from the Mexican collections. Protein values of the progeny of the S_1 ears varied from 12.88 to 17.56 percent.

During 1968 a total of 2,465 corn samples were evaluated for protein and 2,088 for tryptophan.

Future emphasis will be on the development of stocks with high tryptophan using mutants other than opaque-2 and floury-2.

CIMMYT (the Spanish acronym for the International Maize and Wheat Improvement Center) is an outgrowth of 20 years of successful collaboration between the Mexican Ministry of Agriculture and the Rockefeller Foundation in the improvement of the basic food crops of Mexico. These two cooperating agencies initially established CIMMYT in 1963 for the purpose of extending around the world some of the outstanding varieties of wheat and maize and improved production technology. Since 1966 it has operated as an independent international institution. The Government of Mexico provides the home base and participates as an important sponsor.

The strategy of CIMMYT is a multiple attack on the yield limitations of maize and wheat. Its goal is to develop packages of inputs combining the advantages of improved seed, fertilizer, irrigation, and the control of pests diseases and weeds. Results of CIMMYT research programs are already making a notable impact on the agriculture of a number of countries, particularly Mexico, India, Pakistan, and Turkey.

This article is based on a report in CIMMYT News, Vol. 16, Nos. 5-6, 1969, and on private communications from the research staff.

[1] Commonly known as CIMMYT, the initials of the name in Spanish: Centro Internacional de Mejoramiento de Maiz y Trigo.

A NATIONAL ACADEMY OF AGRICULTURAL SCIENCES

ORVILLE G. BENTLEY AND HAROLD E. MYERS

THERE has been a growing concern among the deans of the colleges of agriculture in land-grant universities that the potential leadership capacity among agricultural scientists is not being most effectively organized and used. Because of this concern, the National Association of State Universities and Land-Grant College (NASULGC) appointed a committee in 1966 to investigate the possible need for a National Academy of Agricultural Sciences.

In 1967 the committee reported favorably on the idea. Accordingly, the Overall Deans of Agriculture of NASULGC (those with triple administrative appointments in research, teaching, and extension) decided to continue to explore the question of a National Academy of Agricultural Sciences. Dean Harold E. Myers, University of Arizona, appointed a five-member study committee [1] under the chairmanship of Dean Orville G. Bentley, University of Illinois. The formal report of the committee was presented to the Administrative Heads of Agricultural Programs at the annual meeting of NASULGC in November 1968.

[1] The following are members of this committee: Deans E. V. Smith, Auburn University, Alabama; L. L. Madsen, Washington State University; G. S. Pound, University of Wisconsin; R. E. Larson, Pennsylvania State University; and O. G. Bentley, University of Illinois, chairman.

This article is based on the 1968 committee report and on an address by Dean Myers at the 1968 annual meeting of the Agricultural Research Institute, Washington, D.C.

THE research results that the agricultural sciences have so magnificiently produced in the last century reflect in large measure the quality of leadership within these disciplines. Agricultural research has indeed become a sophisticated enterprise; its long-range viability cannot be disputed.

Despite these achievements, ways need to be sought to increase the leadership role of agriculture in the councils of government and industry. Moreover, the status of the agricultural sciences as an integral and respected part of the general scientific community needs to be fortified.

These attitudes are indicative of the prevailing philosophy of agricultural research leaders and land-grant university administrators. What steps might be taken to add greater unity to the tremendous breadth of the agricultural sciences? In what manner might a common meeting ground be provided for the multidimensional flow of ideas and activity? How can the voice of agriculture at the national level be further enhanced? These were the questions—and rationalizations—that eventually led to the creation of a study committee to consider the possible need for a National Academy of Agricultural Sciences.

The committee saw its task as a study of the need for creating a more effective organization of agricultural scientists—an organization that would serve as a consulting body on the technical and scientific aspects of the Nation's food and agricultural industries, thereby adding stature to the image of agriculture. This paper, as it reflects the committee's views, should be considered as a progress report further delineating the issue.

Position of Agriculture in NAS

THE creation of the National Academy of Sciences more than a century ago proved to be an effective mechanism for stimulating scientific development. As science disciplines developed and expanded in scope, so did the National Academy of Sciences. Membership of the Academy is divided into 15 divisions, 14 of which are recognized disciplines in the area of basic sciences. The 15th is applied biology—the only section which recognizes the scientists who put science to use.

Throughout its 106 years of service, the Academy has undergone several reorganizations and additions. A notable example of this was the creation of the National Research Council (NRC) in 1916. Composed of eight divisions under the Academy, NRC was recognized as a major step in developing the Academy's ability to serve the scientific needs of the Nation.

Upon the recommendation of the Association of Land-Grant Colleges and the directors of State agricultural experiment stations, the Agricultural Board was created in 1944 under the aegis of the Academy and NRC. The Board has four primary functions: (1) To bring together scientific talent of government, industry, and universities into committees to study broad agricultural problems, (2) to collect facts and evaluate present knowledge in relation to agricultural policies and practices, (3) to determine trends and suggest areas of research need, and (4) to disseminate knowledge and expedite the transition of research to practice.

Affiliated with the Agricultural Board is the Agricultural Research Institute (ARI), which was formed in 1951 to provide a forum for discussion of problem common to agricultural scientists. ARI also provides some financial support in both the public and private sectors for the work of the Agricultural Board.

In addition, the Academy has spawned a number of other organizations—such as the American Institute of Biological Sciences, the Building Research Institute, and the American Geological Institute—each of which was organized within the Academy structure and later became an independent or quasi-independent institute.

No one can deny that the Academy is a prestigious organization—one that is held in high esteem by scientists, government officials, and the public. Yet the overall organization does not permit agricultural leaders to assume a role that reflects the national and international importance of agriculture.

Although creation of the Agricultural Board and the establishment of the ARI were significant steps, agricultural scientists are still buried within an NAS administrative structure that was established during the fledgling days of science.[2]

[2] The March 1969 issue of the NAS *News Report* published an interview with Dr. Philip Handler, President-elect of the National Academy of Sciences, in which he discussed some of his views on the Academy, particularly the representation of science disciplines. Dr. Handler indicated that the National Research Council may require restructuring in some ways.

Reasons for an Agricultural Academy

ESTABLISHMENT of an Academy of Agricultural Sciences should be considered from both a scientific and philosophical point of view. Even though adjustments have been made within the National Research Council, these adjustments have not kept pace with the changes in agricultural sciences in the past 25 years. Also, the increased responsibility of agriculture, nationally, and internationally, has created problems and situations that have not been given adequate attention by agricultural scientists in the United States. Consider first the world food problem, as one aspect of the scientific viewpoint of the issue.

Food production and distribution are major problems facing the whole world. The vast areas where substandard nutrition exists and the low agricultural production levels in the developing nations of the world have been the basis for the great emphasis given agriculture through foreign-aid programs of the United States. The rapid increase in world population, especially in the developing nations, compounds the problem.

The lowly social status of agriculture throughout much of the world leaves this most vital of human endeavors largely in the hands of uneducated and unskilled workers. Advances in agricultural science and technology, except those which have been borrowed, have been minimal in the developing nations. The few scientists in these nations who have chosen an agricultural science as a profession come largely from the cities. Because they lack an agricultural background, they cannot really understand farmers or sympathize with them and their problems.

The situation is changing somewhat as more and more young men and a few women who have studied abroad in colleges of agriculture return to their homelands. If this group of educators can be put to productive use in schools, research stations, extension services, industry, and government, we will make a real start toward improving the agricultural production in those areas where more food is vital. Aggressive agricultural leadership is needed on a worldwide basis. Moreover, if this leadership is to be acknowledged and respected abroad, it is imperative that we recognize it first at home.

A philosophical viewpoint of the issue at hand opens up still other aspects that relate to the common concept of agricultural science, or the image it projects to those outside the disciplines.

Because agricultural science embraces a broad spectrum of science under which many specialized areas have evolved, it is not easily defined in precise terms. As in medical science and other broad fields of study, agricultural science is an orientation of disciplines focusing on a particular area. There is a flow of knowledge from the general body of science to agricultural science and vice versa.

Agricultural research, a pioneer in government-sponsored, problem-oriented investigations, has made extensive use of basic research findings from many disciplines. But agricultural research is more than just application of knowledge. By necessity, agricultural scientists have had to involve themselves in basic research directed toward the solution of problems facing one of the world's major industries—agriculture. This intermingling of basic and applied research has added strength to the agricultural research programs.

The results of this application of effort have gone even beyond the world of agriculture. During the pursuit of their primary objective, agricultural scientists have also made many other useful contributions. The discovery and development of certain antibiotics, a commonly used anticoagulent effective in some heart and circulatory diseases, certain vitamins and other nutritional factors, and a host of other discoveries—all are byproducts of agricultural research.

Although it is true that many knowledgeable people recognize the contributions of agricultural scientists to our highly efficient production system, the quality of the image lacks the lustre it justly deserves. As yet we have no fully effective mechanism for acknowledging agricultural leadership and making maximum use of it.

Going beyond these broader aspects of the issue, one can discern other reasons for creating a National Academy of Agricultural Sciences. Among professional agriculturists, institutions, and societies, there is a strong feeling of frustration that they are being constrained by the lack of a powerful, influential agricultural organization. They believe the existing organizations within the framework of the National Academy of Sciences are not effectively presenting their views or exerting an influence that matches the scientific posture of the people in agri-

cultural research and education. Moreover, they feel that inadequate attention is given to the agricultural and food dimensions of national policies—particularly with respect to manpower, resource allocations, and the rising importance of the food industry in the overall economy of the Nation.

There is also a feeling among agriculturalists that their interests are secondary to the basic biological interests in the NAS. In fact, some biologists are seeking separation from agriculture in the Division of Biology and Agriculture. They are asking why biology is not permitted its own integrity. In the AIBS Executive Committee meeting of November 16, 1966, a motion was passed unanimously "that the AIBS President be instructed to write a letter to NAS President Seitz asking that consideration be given to the establishment of a separate division of biology in the NAS–NRC."

The ferment for greater national recognition of agricultural scientists is essentially the same as the one among engineers which resulted in the creation in 1964 of the National Academy of Engineering. This act placed the Engineering Academy on a coordinate basis with the National Academy of Sciences, but under the charter of the NAS. Somewhat the same concern is being expressed by some of the leaders in the medical profession.

Basic Science Vs. Applied

ONE of the basic questions concerning the improvement of status of agricultural scientists seems to revolve around the relative importance of pure and applied science. Engineering, medicine, and agriculture are first and foremost applied sciences. The application of science has been one of the principal factors in the economic development of our Nation. Agriculture, manufacturing, transportation, and health—all have had important roles. Without applied science, basic research contributions would constitute only interesting textbook information. Applied science makes it possible to use basic research results for the benefit of mankind. A sensible conclusion appears to be that both basic and applied research have a high degree of interdependency.

In a 1967 report, "Applied Science and Technological Progress," a committee on science and public policy of the National Academy of Sciences deplored the lowly status of applied research in universities and professional societies. The report states: "Too frequently, however, the general climate in universities and professional societies tends to denigrate the intellectual challenge and satisfaction in applied research; in discovering these things for himself, a scientist or even a research-trained engineer must often overcome adverse attitudes fostered by his graduate studies and professional associations. A greater effort should be made to create an atmosphere in graduate education that would anticipate and encourage the subsequent entry of students into applied work." The report further states: "Raising the status of applied science in universities has become a real problem. The leadership function in applied research is probably more intellectually demanding than that in most basic research."

These remarks aimed at the university are equally appropriate in the world of science and appear to have relevance in the functioning of the National Academy of Sciences which sponsored the report.

Many examples of research achievement could be cited to support the contention that applied scientists—the designers of our remarkable agricultural production system—have had to be men of vision. They have had to learn how to fit together all of the many aspects of science into a single system to obtain maximum economic productivity. All of these examples stand as evidence and justification for strengthening the position of agricultural scientists on the national scene commensurate with the importance of agriculture in our society and the success of the agricultural scientists in contributing to the well-being of all citizens. Such recognition on the national level, in turn, should enhance respect for agricultural scientists on a worldwide basis.

Committee Recommendations

THE five-member study committee has made the following recommendations to the Overall Deans:

1. That the Overall Deans support a study of existing organizations representing natural resources, agricultural, and food scientists. If such a study confirms that a national agricultural organization is needed, the committee should be instructed to develop policy guidelines and to prepare a statement of functions and objectives for a "National Academy of Agricultural Sciences." The committee suggests that the shorter title of "Agricultural Sciences" would be preferable to "Agricultural and Food

Sciences" or "Agriculture and Natural Resource Sciences," and would appropriately identify the function of the proposed academy. The committee includes applicable social and engineering sciences under the broad title of agricultural sciences.

2. That if such an academy is formed, it be under the aegis of NAS, as was done for the National Academy of Engineering, and that only upon failing this endeavor, should consideration be given to forming a separate academy independent of NAS.

3. That the proposed academy would serve science, technology, and education for the benefit of agriculture, government, agribusiness (broadly conceived), and the public interest.

4. That if the study indicates that a new national organization would not be feasible at this time, the committee should consider other, available alternatives. Such alternatives might include: (a) The establishment of a separate division of agriculture within NAS, or (b) expanding the authority and program responsibility of the Agricultural Board. A third alternative, of course, would be to propose no changes at this time.

Objectives of an Agricultural Academy

IF a significant effort is to be made toward the creation of a National Academy of Agricultural Sciences, a great deal of care and attention must be given to developing its objectives and purposes. Without attempting to delineate the specifics, the emphasis should be on providing a medium whereby agricultural scientists and educators could more effectively contribute their experience to pressing national problems and to the advancement of national purpose in the broad field of agriculture and agribusiness.

To illustrate, one can use the example of the newly created National Academy of Engineering. If a National Academy of Agricultural Sciences were created, its objectives could perhaps paraphrase those of the National Academy of Engineering:

1. To provide means of assessing the constantly changing needs of the Nation and the technical resources that can and should be applied to them; to sponsor programs aimed at meeting these needs; and to encourage such agricultural research as may be advisable in the national interest.

2. To explore means for promoting cooperation in agriculture in the United States and abroad, with a view toward concentrating on problems significant to society and encouraging research and development programs aimed at meeting these problems.

3. To advise the Congress and the executive branch of the Government on matters of national impact pertinent to agriculture.

4. To cooperate with the NAS on matters involving both science and technology.

5. To serve the Nation in other respects in connection with significant problems in agricultural science and technology.

6. To recognize in an appropriate manner outstanding contributions to the Nation made by leading agricultural scientists.

Many of the functions now performed by the Agricultural Board and the Agricultural Research Institute should become the function of a National Academy of Agricultural Sciences. All leaders in agricultural sciences should be eligible for membership in a National Academy of Agricultural Sciences, even if their special interests be in the general areas defined by physical, chemical, biological, or social sciences.

In general, the structure and function of a National Academy of Agricultural Sciences should bear the same relationship to disciplines and problems in agriculture as the National Academy of Sciences bears to pure science disciplines. Those agricultural science areas recognized by the established professional societies should be the guide for establishing sections in the proposed Academy.

The Attendant Problems

ALTHOUGH the idea of forming an Academy of Agricultural Sciences has generally drawn favorable support among the agricultural disciplines, some perplexing questions have been raised about matters of prestige, leadership, financing, and recognition.

One of the questions most frequently raised is whether such an academy might be considered second-rate to the National Academy of Sciences. In other words, would membership in the new academy carry less prestige than membership in NAS? Such an expression would lead one to believe that the National Academy of Sciences is merely an honorary society. Although membership is coveted by good scientists, the National Academy of Sciences is a functioning society. Its purposes are far greater than honoring elected members, and a brief review of its

organizational setup substantiates this viewpoint. NAS members, elected on the basis of scientific accomplishments mostly in the basic science disciplines, direct the activities of the National Academy of Sciences. Actual control of the Academy is vested in a 17-man Council, consisting of five elected officers of the Academy and 12 additional members. Since the membership of the Academy of Sciences is ultimately responsible for all of the work done by the overall organization, and since the Agricultural Board and the Agricultural Research Institute are under the Division of Biology and Agriculture of the National Research Council—which in turn is under the Academy—agricultural scientists are relegated to a distinctly subordinate position in the organization.

The study committee was well aware of a number of other basic questions that must be considered prior to initiating action.

1. Could sufficient cohesion be developed by the professional and scientific societies and the colleges of agriculture to speak with a common voice?

2. Could the necessary financial support be obtained from agricultural industries and foundations? The costs would undoubtedly be substantial. But if an academy is to have a sound financial base, its financial obligations must be critically and realistically appraised. The National Academy of Engineering had an initial annual budget of $100,000. If funds are to be raised from industry, liaison with such organizations as the Agricultural Research Institute will be needed. There is also a need to coordinate the discussion of financial obligations with the Agricultural Board of the National Research Council. ARI was created, in part, to provide a mechanism for obtaining financial support for worthy projects recommended by the Agricultural Board.

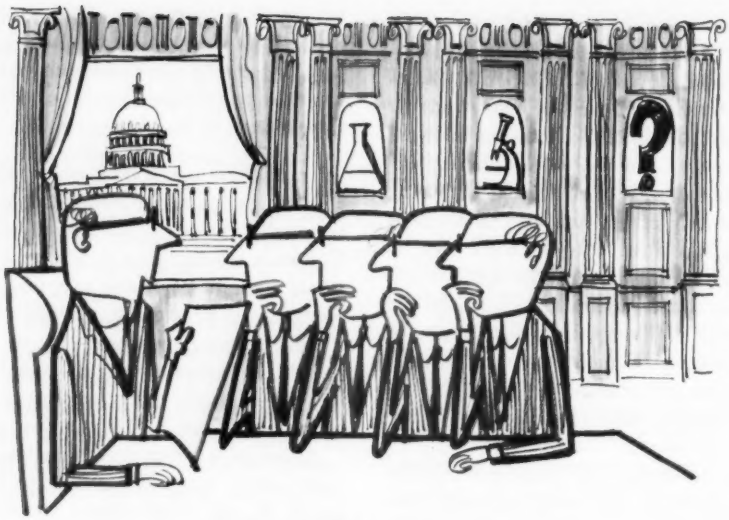
3. What leadership could be developed that would be recognized by all agricultural groups? Would the land-grant colleges, for example, be sufficiently dedicated to provide sustained leadership?

Conclusions

IF ever there was a time when aggressive and respected agricultural leadership is needed—both nationally and on a worldwide basis—it is today. The issue touches on a significant dimension of national and international scientific posture. A few statistics will bear out this significance. About $900 million is being spent annually on agricultural research by government, universities, and industry. The scientific manpower to carry out these programs now totals 26,000 scientist man-years.

Although it is true that many fine, progressive organizations, associations, and societies contribute much to the professional development of the scientists conducting these programs, they lack a strong, national body to speak for them—and to speak for agriculture. The fact that there are so many diverse professional groups tends to fragment research. They represent segments; they speak singly, not as a unified group mobilized for a common purpose.

What is needed is a mobilization of the creative manpower in agricultural science through the establishment of a National Academy of Agricultural Sciences. Such a prestigious body—representative of the whole of agriculture—would help set solid standards of leadership on a worldwide basis. For, indeed, the spectacular and ingenious use of applied research has given agricultural scientists the responsibility of primacy. They have proved their capabilities; they have earned their mettle in their respective disciplines of science. Is it not the time, therefore, to provide a fully effective mechanism for acknowledging this leadership and making maximum use of it?



A SYSTEMS APPROACH TO THE ORGANIZATION OF AGRICULTURAL RESEARCH

FRANCES M. MAGRABI

BECAUSE of the rapid and incessant change in agriculture, questions about the efficiency of research and the wise use of resources are becoming more and more critical. The situation is being viewed with considerable concern, both in the U.S. Department of Agriculture and in the States. To some extent, this concern has probably been due to an increasing shortage of funds available for research support. But whatever the cause, all phases of the research process have been intensively scrutinized in an effort to improve the efficiency of use of the available research support. In general, three kinds of effort can be identified: (a) Efforts to reallocate funds to more nearly match the importance and urgency of agricultural problems, (b) efforts to reallocate funds according to the productivity of individual research projects and program areas, and (c) efforts to improve the productivity of research.

Problem Priorities.—A major study by a joint USDA–SAES task force represented one of the first efforts to reallocate funds on the basis of problem priorities. In its report, *A National Program of Research for Agriculture,* the task force identified 10 national goals for agriculture, and recommended the degree of support needed for adequate progress in each area (*18*).[1] Closely related to these efforts were the compilations of current research published as *An Inventory of Agricultural Research,* Volumes I and II, 1967, and the initiation in the USDA of the Current Research Information System for generating, as needed, the information required for effec-

[1] Italic numbers in parentheses refer to "Literature Cited," p. 32.

tive research program management. These activities have been supplemented by similar efforts in various State and Federal committees and task forces, and are aimed at extending, revising, providing detail, or relating the program plans to the needs of each individual State, region, or field of research.

Program Productivity.—Little can be accomplished by spending money on an important research area if useful results cannot be generated. Hence, much thought and discussion have been devoted to groundwork for reallocating research support in accordance with the productivity of projects and program areas. *A National Program of Research for Agriculture* included suggested criteria for evaluating the expected productivity of the research (*18*). The Planning, Programing, and Budgeting System, first used in the Department of Defense and adopted governmentwide in 1965, also contributed to this effort by emphasizing the necessity for systematic evaluation of program output. The theory and strategy of programs for research or action have been discussed in a number of publications (*5, 8, 9, 12, 14*), culminating in the recent conference jointly sponsored by the University of Minnesota and the USDA in February 1969 on "Resource Allocation in Agriculture Research."

Research Improvement.—Efforts have been made at all levels—managerial, theoretical, and technical—to improve the effectiveness and efficiency of carrying on research. New techniques, procedures, and instrumentation have been tried. There is increasing emphasis on improving the quality of scientific and administrative activities through conferences, seminars, and other educational activities.

Such activities are all worthwhile, but have absorbed substantial amounts of time and money. In fact, a frequent plea from scientist and administrator alike is to be allowed to "get on with the job." To a degree, the complaints are justifiable. They would be more serious if the planning and evaluation attempts could be categorized as random and unscientific, rather than rational and organized. Actually, serious attempts have been made to apply scientific theory to research planning and management, as, for example, the recent efforts to apply economic models to the problem of evaluating research productivity (*8, 9, 14*).

An avenue just beginning to be explored, general systems theory, has a considerable application to the organization of agriculture research (*15*). A translation into theoretical terms of the agents and activities in research can at least provide an overview of the total situation, and may suggest questions which ought to be answered.

The purpose of this paper is to describe the present organization of agricultural research as a social system. The relationships among system elements can be viewed in two ways—first as a set of input-output relationships depending primarily on incentives, and second as a communication system.

Social System Formulation

ALL social systems, according to Katz and Kahn, are composed of ". . . patterned activities of a number of individuals . . . complementary or interdependent with respect to some common output or outcome; they are repeated, relatively enduring, and bounded in space and time . . ." (*11*). Organizations are a subclass of social systems. A social organization has within it an authority structure and structures for: (a) Maintaining itself, (b) producing output, (c) performing functions necessary for production of that output, and (d) adapting itself to a changing environment. A social organization has an elaborated, formal role pattern. Specific functions are assigned to specific roles. Its ideology provides norms for performance of functions, especially with respect to the authority structure (*11*).

Conceptualized as a system, the agricultural research establishment includes partially or wholly within its bounds several social organizations. This system is open, complex, and adaptive. Four principal kinds of roles are included in or relevant to the system: (a) Scientists who perform the research, (b) research administrators, (c) users of research, and (d) those who provide or approve funds. Organizations in the system include land-grant and certain other colleges and universities (*7*), and several agencies in the USDA itself. Closely related are the Federal and State legislatures and certain other Federal agencies (e.g., Bureau of the Budget) which are responsible for funding research, and the agricultural research users including individual farm families and agribusiness establishments and associations. Obviously any one individual may belong to several organizations. For example, the experiment station scientist has a role in relation to the Cooperative State Research Service in the USDA,

which administers some of the funds which support his research and pay his salary. But the scientist is also a member of the faculty at his college or university and may have teaching responsibilities and committee assignments. He is also typically affiliated with one or more professional organizations in his discipline.

All of these organizations are interdependent. Colleges and universities depend on funds administered through the USDA for supporting some of its research activities, and also upon the scientists who add to the prestige of the university and may perform teaching or administrative duties. The USDA in turn, depends, on the universities not only for program implementation, but also for providing trained personnel. Universities also provide a setting for some of the research performed by USDA employees. Both the USDA and colleges and universities depend on legislatures for funds and legal authority, and they have a service relationship to the agricultural community (farmers, agribusiness, farm families, and consumers of agricultural products), in that these are the ultimate users of the research findings produced by USDA and SAES scientists. There is also a group of intermediate users—extension workers, teachers, and others who transmit and interpret research results to those needing the information.

The agricultural research system is open in the sense that it depends on inputs from the environment and produces an output (research-based information) which passes into the environment. The most obvious inputs from the environment include appropriated funds; gifts and grants from business, foundations, and individuals; data from the physical environment or from people; and communications from other scientists.

The agricultural research system is complex and adaptive in the sense described by Buckley, ". . . open 'internally' as well as externally in that the interchanges among their components may result in significant changes in the nature of the components themselves with important consequences for the system as a whole." (*4*) An example is the interaction between CSRS and State experiment stations in which procedures and policies, such as those for approval and review of research projects or allocation of funds, are frequently modified as a result of joint discussions. These information flows between components ". . . make possible not only self-regulation, but self-direction or at least adaptation to a changing environment, such that the system may change or elaborate its structure as a condition of survival or viability." (*4*) Clearly, the recent attempts to formulate and implement programs of agricultural research are efforts to adapt to a changing environment and give self-direction to the system.

Certain other characteristics of social systems (*11*) have significance also. Systems are cycles of events. In the agricultural research system, the cycle is clearly defined—at least in theory. Problems needing research are communicated to the scientist from the environment. Other scientists or research administrators may act as mediators in this phase. A scientist or a group of scientists designs a study to obtain information needed to solve the problem. The proposal is reviewed for importance, feasibility, technical and scientific soundness, etc., by a hierarchy of administrators and, if approved, it is funded. Space, equipment, and technical assistance are provided through the administrators. Scientists carry out the research, more or less as planned, and write a report which is made available to those elements in the environment involved in the original problem. The aid given by information in the report produces results which in some fashion—such as increased profits in agriculture or improved well-being of farm families—induce legislators and potential donors to make funds available to support new research. Thus the cycle is complete.

Two other characteristics of social systems in agriculture are: The tendency towards increasing differentiation of parts, and the tendency to maintain a steady state or dynamic homeostasis. All organizations or systems are subject to entropy; that is, the tendency to disintegrate into a disordered state. The steady state is maintained through the intake from the environment of negative entropy, which in agricultural research takes the form of money and facilities for performing the research plus a whole range of incentives to induce individual scientists and administrators to perform given roles within the system and conform to established norms. The system may, in fact, take in more of these resources than are required for the current maintenance of the system and either use the surplus to expand or elaborate the system or store it, as, for

example, by building excess capacity in facilities and equipment which can tide the system over during periods when inputs are scarce (*11*).

A tendency towards increasing differentiation and elaboration is readily observable in the history of the agricultural research system. Scientists and administrators perform increasingly specialized functions within their organizations. Committees and agencies are formed with specific charges and responsibilities which may later be divided among several new agencies or committees. In part, the increasing differentiation serves to improve the efficiency of the system for producing its various outputs. The elaboration of structure also absorbs resource input, however, so that increasing amounts of resources must be allocated to system maintenance rather than productive functions.

The Incentive System

ALL organizations, according to Argyris, perform three core activities: ". . . achieve the organizations' goals (i.e., the consequences for which they were intended) . . . maintain their internal system, and . . . integrate themselves with their environment." (*2*) It is apparent that either the first or the second activity might be taken as the central purpose of the organization. In an open system, the input of resources—especially material ones—is usually one of the easiest processes to measure. Achievement of organizational goals is frequently more intangible and elusive to measure, especially for agricultural research—the goals of which are usually vaguely specified as to: (a) The exact group of people having the problem, (b) the precise nature of the problem, and (c) what an acceptable solution is. Furthermore, goal accomplishment is usually thought of as being in the future, and depends on actions of other agencies.

Yuchtman and Seashore, in their proposed framework for the assessment of organization effectiveness, state the proposition that ". . . the highest level of organizational effectiveness is reached when the organization maximizes its bargaining position and optimizes its resource procurement." (*17*) This definition of effectiveness, based on an open systems model of social organizatons, focuses on the relations between the organization and its environment, especially the ability of the organization ". . . to exploit its environment in the acquisition of scarce and valued resources." (*17*)

In a similar vein, Clark and Wilson, on the assumption that individuals participate as members of organizations because of incentives, state that ". . . the incentive system may be regarded as the priniciple variable affecting organization behavior." (*6*) They distinguish types of incentives as being: (a) Material—salary or other tangible rewards; (b) intangible—the status resulting from membership, and maintenance of social distinctions; and (c) purposive—those which derive from the stated aims of the organization.

Organizations in the agricultural research system seem to rely mainly on material incentives, although they get an important assist from solidary incentives—recognition from colleagues for papers published in scientific and professional journals, the prestige of being attached to a university, the deference accorded to certain statuses within the organization, the awarding of such amenities as a private office, secretary, and technical assistants, and power which an individual may exercise within or outside the organization. Purposive incentives—the desire to benefit humanity or add to scientific knowledge—are, of course, not lacking.

Because of emphasis on resource input, the concept of representation between groups becomes especially important (*16*). Certain individuals within the organization are assigned as their special function that of representing their organization in its interaction with other organizations. Those individuals who have, or are presumed to have, prestige and influence in the other organization are likely to be selected as representatives, especially if the interaction is with more powerful organizations or those on which the original organization is dependent. Conversely, the role of representative in dealings with a more powerful organization confers power and prestige on the individual within his own organization, especially if he is successful in obtaining the desired inputs from the other organization.

As an illustration, CSRS has the role of the intermediary between State experiment stations and Congress. It presents and justifies budget requests and administers the appropriated funds. Within the State experiment station, the directors and department chairmen, at different levels, each represent their own groups in dealing with other organizations or parts of the same organization. However, individual faculty members often acquire power

within the organization by demonstrating their ability to attract research funds from foundations or other donors.

If we assume that an agricultural research system must depend on incentives to remain viable and to achieve stated goals, the question needs to be answered: Is the current system of incentives the most effective one? Could it be supplemented by other incentives? Incentives seem to be awarded to the individual scientist roughly in proportion with the number of papers he publishes. Special emphasis is given to papers published in scientific periodicals as opposed to popular ones, and to the amount of outside research support he obtains. Influence with powerful outside agencies, as exhibited through membership on committees and boards or through awards and speaking engagements, also have their effect. An objection to these practices is their lack of direct relationship to solution of problems of research users (*10*). The persons having the problems—farm operators, consumers, etc.—are not notable for their readership of scientific journals. Interpretation of results in popular publications and educational or legislative or regulative programs usually requires another set of operations not normally performed within the research system. The situation might be improved if steps were taken to give greater recognition and rewards to those who interpret research results for general use. Such action might induce research scientists to give greater attention to this important step in the research cycle.

A similar issue emerges as to the makeup of task forces responsible for formulating goals and priorities for agricultural research. A very high proportion of the members are usually in administrative positions within the agricultural research system. In other words, one thing most of them have in common is a high degree of control over money incentives. Presumably, these persons are in a good position to know what research has a good chance of being funded. Whether they are also aware of the needs of users of agricultural research is less obvious and probably depends on how active they have been in making contacts with and studying communications from users. Including more research scientists in the rosters of task forces would not necessarily improve the situation, since few scientists are likely to have broader contacts with research users than their administrators. Users might be better represented if a higher proportion of teachers and workers in extension and action programs, directly representing groups of research users, were included in task forces for identifying research needs and priorities.

The Communication System

ONE cannot discuss the agricultural research system without frequent reference to communications (*3*). Some insight into what makes a system effective can be obtained by focusing exclusively on agricultural research as a system of communications—particularly communications that consist of inputs and outputs of the system. Quality of communications should be emphasized; that is, the amount of information in the messages, and the strategic location within the system of the senders and receivers of messages. Ackoff's proposed framework (*1*) for measuring the value of communication seems to be especially applicable in that it can be used for communications occurring at any stage of the research cycle. When aplied to communications reporting research results, it is quite similar to conventional economic models.

Information flows within the agricultural research system require not only inputs, but also feedback and coding. Information inputs from the environment are filtered or coded in various ways. For example, not only research administrators, but various advisory committees, such as the Agricultural Research Policy Advisory Committee, evaluate information concerning research needs in agriculture. This information, after being coded into priority and policy statements, is used to guide activities within the research system. At a later stage of the research cycle, scientists gather from the environment data relevant to solving problems of agriculture and code it according to accepted principles of scientific methodology. It is this coded data which is used in formulating and testing solutions to problems. The reporting phase of the research involves another coding step, when results couched in scientific terminology are restated, that is, recoded, in language directly relevant to the specific problem in the environment and understandable to individuals who are active in solving the problems.

Feedback processes have been established and carefully maintained to ensure that the research system is conforming with approved priorities and policies and with legal and other requirements. These feedbacks are internal—within and between

organizations within the system, and external—between the system and its environment. Various reports such an annual progress reports and financial reports are used for internal feedback. External feedback ranges from informal comments by legislators reviewing budget requests and scientists reflecting on the state of agricultural research, to carefully tested and documented evaluations of the effectiveness of completed research for solving agricultural problems.

In emphasizing the relationship of communication to decision, Ackoff (*1*) identifies as elements in his framework: (a) The purposeful individual or entity (in the agricultural research system this would correspond to the farm operator or consumer who has a problem), (b) courses of action relative to the problem, (c) outcomes or consequences of action, and (d) the respective values of these outcomes as solutions to the problem. An available course of action is one that is a possible choice within the environment of the individual. A potential course of action is one which has a probability greater than zero of being chosen by the individual.

Communication, then, is a set of signs that influence either an individual's choice among the alternative courses of action or the outcome of his choice. It may influence him either by: (a) Informing him about available courses of action and their probable outcomes, (b) improving through instruction his control over the outcomes of any specific action, or (c) motivating him to choose a specific action through changing his evaluation of outcomes.

Each of these three types of message content—information, instruction, and motivation—can, at least in theory, be measured. To do this, one needs to determine: (a) The probability that any specific action will be taken by the individual (both before and after the communication occurs), (b) the probability that any specific outcome will occur for any given action (both before and after the communication occurs), and (c) the before-and-after values of the various outcomes.

It is clear that agricultural research encompasses all three types of content. Some projects focus on finding new alternatives for solving problems, others on identifying optimum methods of performance. Still other projects focus on ways of changing attitudes, and motivation and facts needed to change attitudes. Some studies on the effects of pesticides, for example, are intended to change the probability that an individual farm operator will choose a particular course of action (application of a specific pesticide) by informing him of its effectiveness for achieving some outcome he will value. Other studies aim at increasing the likelihood that a desired outcome will be achieved, assuming that a particular course of action is chosen (for example, studies of the relative effectiveness of alternative methods of pesticide application). Still others, such as studies of the effects of pollution in the environment, are intended to alter the evaluation of outcomes (for example, whether increased farm production is worthwhile at the cost of a polluted environment). If the results of research programs are to be evaluated, the evaluation should measure the specific effect intended.

Questions which might be raised about research as a communication system are: To what extent are communications directed and adapted to the intended recipients? For example, are reports of completed research directed to users rather than professional colleagues? Is the content—information, instruction, motivation—appropriate to the problem? Have efficient channels of communication been established between those parts of the system which must communicate if the goals are to be achieved? For example, is there easy and direct communication between those actually experiencing needs for research information and those who decide what research shall be done? Who should properly decide what research should be done? Should it be the administrator, the scientist, or the funders of research representing the research users? Who is in the best position to know what research is needed, what research activity can be supported, and what research is feasible and is likely to have the highest productivity in terms of additions to knowledge?

Focusing on actual content of messages—reports on operations, reports of research findings, policy statements, etc.—what amount of information does the message actually contain? Is the information perhaps redundant, inaccurate, irrelevant? Again, who is in the most strategic position to answer these questions, and what additional information must be provided for a sound evaluation?

And, with respect to implementing recommendations of the various task forces on research needs and program goals, what communications are needed among scientists to stimulate and coordinate

research? What communications will be most effective for informing agents in the environment—legislative bodies and other sources of research support, action agencies, educators, extension workers—about the content and effective operation of agricultural research and for obtaining necessary feedback and resource input?

All of this adds up to one general question: How well does agricultural research function as a total communication system? Clearly we have a complex set of processes for gathering information from the environment, for processing it and feeding back newly created knowledge into the environment. Each communication link must be scrutinized in relation to the productivity of the system.

Conclusion

CONCEPTUALIZING the organizations in agricultural research as components of a social system seems to have some merit as a framework for viewing various policy and procedural questions. It also makes possible the application of theories of social organization and communication, or, on a more abstract level, the emerging theory of systems in general (*4*). In this paper, questions have been raised about the effects of patterns of incentive and improved effective communications on research output. Probably equally important would be an analysis of the power structure as it applies within and between the related organizations (*13*).

It is evident that current efforts at self-examination, reorganization, and redirection now underway in the agricultural research establishment are earnest attempts to adapt to changing environmental needs and pressures and make the output of the system increasingly efficient and effective in solving urgent social problems. To aid and coordinate these efforts, relevant theories must be examined and applied. Otherwise, too great a proportion of the limited resources available for research may be diverted to maintenance of the system and not enough to production of vitally needed research findings. The systems theory approach can be helpful in focusing attention on the cyclical nature of the research process, the relevance of research communication to decisions, and on those other characteristics and processes which give direction and vitality to the total research effort.

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AGRICULTURAL RESEARCH Patterns for the Future

PHILIP HANDLER

ON February 24, 1966, the author of this article was one of the participating speakers at an Airlie House symposium where some of the Nation's top scientists had gathered to ponder role, capacity, and needs of agricultural research. At that time Dr. Handler was chairman of the Department of Biochemistry, Duke University. On July 1 of this year, he became the 18th president of the National Academy of Sciences.

Dr. Handler's presentation at the symposium included some particularly significant commentary on the research needs of agriculture as they relate to the missions of the Department of Agriculture. Because of his views as Academy president on the role of that institution in the scientific community, including agriculture, it seems especially appropriate to reprint here selected sections of his earlier commentary from the proceedings of that occasion.

The fact that the present pattern of research matches fairly well what Dr. Handler advocated nearly 4 years ago does not necessarily imply that his thinking wrought such influence. But it does seem singularly appropriate to note that, in several of the research areas he mentioned, research activity has accelerated and a dream or two of the new Academy president have become realities.

IN viewing the future of American agriculture, we commence from a position of great strength, as we are all aware, of a readily available surplus in the soil bank. From the standpoint of the planet, however, we look to the future from a position of weakness and an awareness that world agriculture, even now, is insufficient to world need.

It appears ever more urgent that agriculture and botanical research be pursued with a maximum vigor to meet the production goals for the next century. If scientific agriculture is to flourish, the science upon which it rests must flourish also. Those responsible for our national program in agriculture must accept responsibility for support of fundamental research in the sciences which underpin it.

This cannot be done by restricting support to the inhouse laboratories of the USDA—no matter how liberal their research policies—nor to the agricultural experiment stations at the land-grant universities. There must also be a vigorous program of support for the well-springs of related science, regardless of where these may be. As a dividend, bonds are created between the USDA and first-rate academic scientists the Nation over. And they may well

prove to be agriculture's most precious resource!

Areas of Research Need

A number of areas of research appear to be significant at this time and most likely to produce understanding which can be translated into useful agricultural practice.

- Chemical weed killing bids fair to eliminate one of the most ancient and backbreaking of man's agricultural labors. Research must continue to unravel the secrets of plant physiology in the hope that new leads will open the way to specific weed killers, and to phenomena and application of which we have no vision at this moment.
- The exciting work led largely by Sterling Hendricks at Beltsville has opened new vistas of understanding of the light-detecting systems of plants and the manner in which they operate to control the time of flowering. It seems entirely possible that pursuit of these mechanisms may yet make possible external control of the flowering process, for example, by chemical sprays.
- Understanding of plant endocrinology is as yet quite primitive. Further integrated studies offer the opportunity of much more precise control of plant culture.
- Cultivation of intact plants from single cells has been demonstrated in the laboratory and opens the possibility of revolutionary approaches to plant propagation and genetic manipulation.
- The ochre mutant of maize which has an unusual abundance of lysine has been much publicized. Undoubtedly, a strain of corn with an amino acid composition more closely approximating the balanced mixture required by man would be an enormous boon to mankind. The same approach should systematically be pursued for other plant forms—even wheat and rice.
- There should be a continuing cataloging and examination of the possibilities for human nutrition of the thousands of plant species which have hitherto not been considered. Indeed, it is about time to plan, on paper, the perfect food crop and breed toward it from the most appropriate starting material.
- Hybrid vigor or "heterosis" is incompletely understood and does not operate consistently in the desired fashion. Surely the biology of heterosis is deserving of the most intensive attention.
- Each of the principal food crops warrants intensive study with respect to nutrition, conditions of culture, and the continuing development of new strains.
- Research should be stepped up in seeking genetic strains with minimal requirements for water and searching for agents which can alter stomatal physiology to reduce water requirements. If such a program were successful, it would open large areas of the earth to productive agriculture—areas which are now marginal because of limited water supply.
- Only a small fraction of the total plant cover of the planet is potentially available as human food. We utilize mainly seed parts, whereas the leaf—the chemical factory of the plant—is rich in vitamins, minerals, and its proteins. Surely this justifies a vigorous program for new technology whereby the components of the leaf can be made available as a supplement to the human dietary.

N. W. Pirie has been active in this kind of research in the laboratory while proselyting others to this cause abroad. But he lacks company and a concerted effort in this regard.

- In our country the time is far off before we need contemplate developing the use of algae as primary food for man. But algae may very well hold the answer to how we shall manage to continue to enjoy something like our current bountiful supply of animal protein.

It seems unlikely that there is any point, at this moment, to recommend a specific program on the production of algae. But until that time comes, it would be well to embark on a serious program of basic studies on algal growth, development, nutrition, and photosynthesis.

- Man has probably discovered the best plant sources to provide his major food energy requirements. At least those which we utilize have remained unchallenged since the dawn of recorded history. Although research continues to improve these sources, we may not find any new crop of major importance as food unless it be among the lower plants. But we have only just begun to recognize the chemical storehouse that is the plant kingdom. Surely, continuing

systematic investigation will reveal new oils, waxes, gums, new fibers, new drugs, and perhaps even new compounds for the control of plant parasites themselves.

- No creature has so altered the ecology of his surroundings as has man himself. Our understanding of ecology systems, both small and large, is rather dim. It behooves us to continually refine our ecological understanding if we are to avert disaster as, by diverse procedures, we attempt to control our environment.
- The science of entomology has contributed much to agriculture. But for more than a generation this science had become almost moribund. The use of chemical insecticides in the last several years has resulted in a small renaissance in this discipline, if you will. But surely the efforts to date have been insufficient; our approaches to insect and pest control generally must certainly be in their infancy. If more efficient and effective chemical weapons are to be designed for this arsenal, it can only be done with a much more intimate understanding of the anatomy, physiology, development, and behavior of the insect forms with which we are concerned.

As a biologist it is my hope that with sufficient understanding we can minimize the use of chemical pesticides. In the end, we shall probably be forced to compromise between the hope of total eradication of a pest with a chemical and settle for biological control which is unlikely to be complete but can reduce damage to an acceptable minimum.

Behavioral control of insects is a highly attractive possibility for the future. Since insect behavior patterns are commonly steered or regulated by chemicals or other types of signals produced by the insects themselves, there is often the opportunity to direct the insects away from their normal source of nutrition—the crop plant.

The success of the USDA laboratory at Beltsville in isolating, identifying, and synthesizing the sex attractant of the gypsy moth is a landmark in the history of this approach. But there must be many other sensory cues that are species-specific, and interference with these cues by broadcasting a sex attractant or a food attractant should provide specific and highly effective ways of misdirecting pests.

Basic research on chemical communication among insects and on the effects of chemical stimuli on insect behavior should be a richly rewarding field and warrants generous support. Let us have a modern entomology!

- It gives me both great satisfaction and a sense of frustration to note that it has been possible to breed and select strains of many crop plants that are specifically resistant to one or another attacking micro-organism, virus, or predator. But there can be no gene specific for resistance. Such a gene must control some aspect of the intrinsic biology of the plant—the indirect consequence of which is resistance to an infection or predator when that chance arises. If we could identify that aspect of the plant's life, we would be further along the highway of understanding, and, hence, useful control.
- Finally, I can only urge attention to wild, "way-out" ideas. The time is not today—but tomorrow we shall learn to fertilize and farm offshore waters, rivers, and our large lakes; perhaps we shall manipulate the great upwellings—or generate our own—and thus decide where to "farm" the sea, "calling our own shots." The algal blooms that are now a great nuisance in our rivers should either be eliminated—so the fish will survive—or be harvested and become poultry, hog, or fish food.

The dinoflagellates, now a great nuisance, can with imagination, also serve as a way to expand our animal protein supply. There are other photosynthetic organisms which, per square foot or per acre, are considerably more efficient as light energy traps and synthesizing machines than are our traditional crops. How can we use them? No ideas should be rejected simply because they are unconventional—let us try them all.

* * *

Much must be done if we are to provide the scientific underpinnings of a modern agricultural technology. The sophistication of that technology to date is the platform on which rests the remarkable affluence and sense of well-being of American society as it enters the age of scientific revolution. It is that technology which has made it possible for one man to feed 40 of his fellows—freeing those fellows to develop still other technologies or to explore beckoning avenues of the spirit and of the mind. If it be at all possible, we must offer that same prospect to our children's children—not only in our own land, but in all the far corners of the earth.

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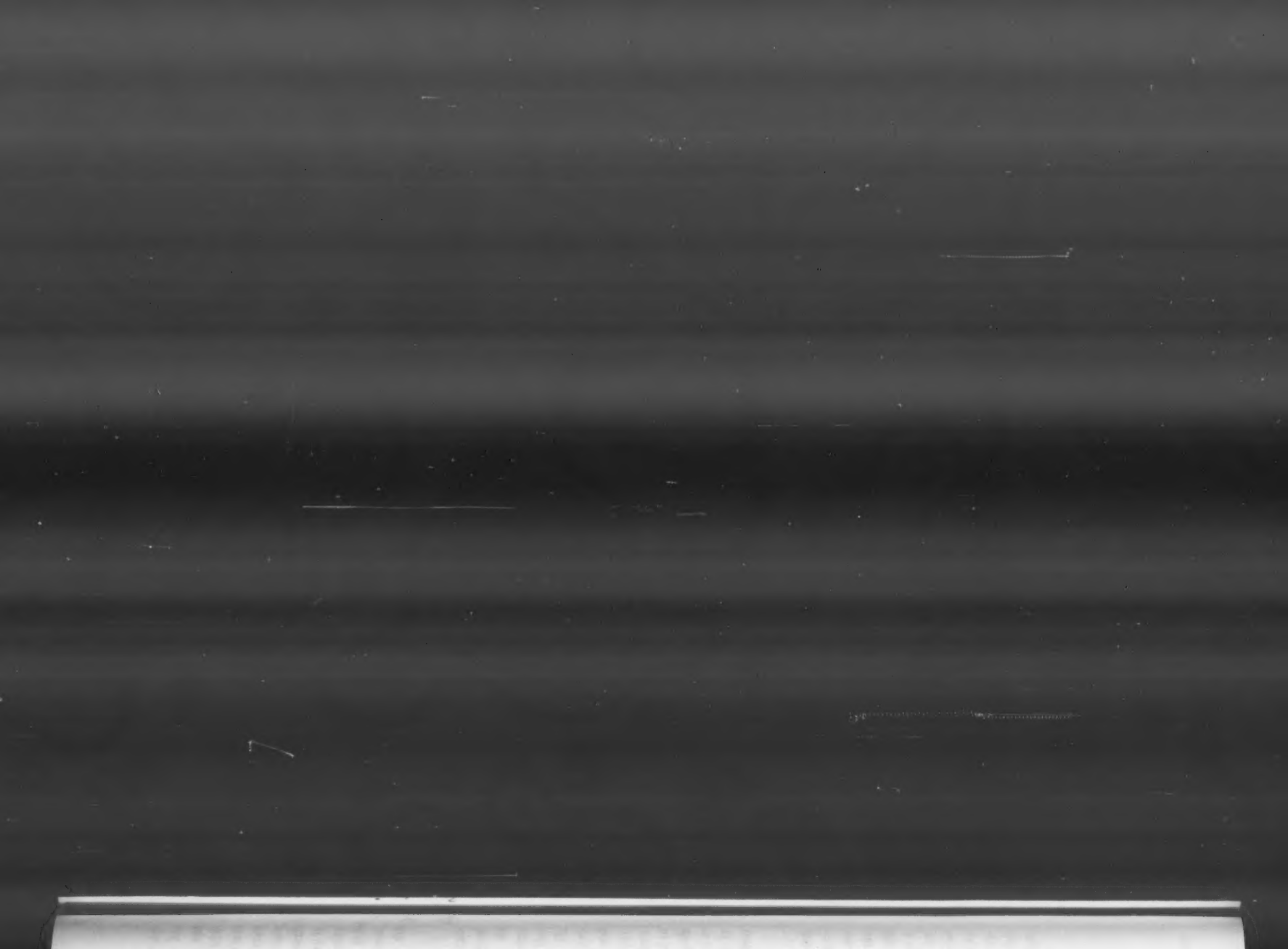
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